

Project 33.2

GEOLOGICAL, GEOPHYSICAL, CHEMICAL, AND HYDROLOGICAL INVESTIGATIONS OF THE SAND SPRINGS RANGE, FAIRVIEW VALLEY, AND FOURMILE FLAT, CHURCHILL COUNTY, NEVADA

Nevada Bureau of Mines

DISCLAIMER NOTICE

THIS DOCUMENT IS THE BEST QUALITY AVAILABLE.

COPY FURNISHED CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

H. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such ampleyee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

Printed in USA. Price \$7.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Va.

BLANK PAGE

STATE OF NEVADA

GRANT SAWYER, COVERNOR

UNIVERSITY OF NEVADA

CHARLES J. ARMSTRONG, PRESIDENT

NEVADA BUREAU OF MINES
NEVADA MINING ANALYTICAL LABORATORY
VERNON E. SCHEID, DIRECTOR
S. E. JEROME, ASSOCIATE DIRECTOR

DESERT RESEARCH INSTITUTE WENDELL A. MORDY, DIRECTOR

FINAL REPORT

GEOLOGICAL, GEOPHYSICAL, CHEMICAL, AND HYDROLOGICAL
INVESTIGATIONS OF THE SAND SPPINGS RANGE,
FAIRVIEW VALLEY, AND FOURMILE FLAT,
CHURCHILL COUNTY, NEVADA

For

SHOAL EVENT

PROJECT SHADE, VELA UNIFORM PROGRAM
ATOMIC ENERGY COMMISSION

Ву

NEVADA BUREAU OF MINES
NEVADA MINING ANALYTICAL LABORATORY
DESERT RESEARCH INSTITUTE

UNIVERSITY OF NEVADA RENO, NEVADA 1964

TAPLE OF REPORT SUBDIVISIONS

		Page
FOREWOR	D	. 1
PARI I.	SHOAL EXPLORATION STAGE	. 2
	Geological, Geophysical, and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada.	
PART II	. SHOAL OPERATIONAL STAGE	148
	Section A	. 148
	Geological, Geophysical and Chemical Investigations of the Shoal Site, Sand Springs Range, Churchill County, Nevada.	
	Section B	238
	Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada.	

BLANK PAGE

FOREWORD

This final report covers all investigations by certain personnel of the University of Nevada for the United States Atomic Energy Commission in connection with its Shoal nuclear event. Authors are listed under the titles for which they are responsible.

Part I is basically that report transmitted in September 1962 to Mr. James E. Reeves, manager of Nevada Operations, United States Atomic Energy Commission by Dr. Charles J. Armstrong, president of the University of Nevada. A second report, much of which is included here in Part II, Sections A and B and covering investigations up to and immediately subsequent to the Shoal detonation, was transmitted to Mr. Reeves by Dr. Armstrong in December 1963. Chemical and nydrological investigations have continued to the present time.

The first report, accompanied by a large map folio, was printed in a limited edition of 200 copies. Only 30 mimeographed copies of the second were made, and of course it lacked the work completed since December 1963. Publication of this report by the United States Atomic Energy Commission insures distribution to all persons interested in the techniques and results of the University of Nevada's program.

This volume is accompanied by a box containing 12 plates. Plates 1 through 8 are the principal illustrations for Part I. Plates 8 through 12 pertaining to geological and geophysical logs of Drill Holes are discussed in Part II, Section A.

S. E. Jerome Shoal Project Engineer University of Nevada

PART I

SHOAL EXPLORATION STAGE GEOLOGICAL, GEOPHYSICAL, AND HYDROLOGICAL INVESTIGATIONS OF THE SAND SPRINGS RANGE, FAIRVIEW VALLEY, AND FOURMILE FLAT, CHURCHILL COUNTY, NEVADA

Ву

PERSONNEL OF

NEVADA BUREAU OF MINES

NEVADA MINING ANALYTICAL LABORATORY

DESERT RESEARCH INSTITUTE

UNIVERSITY OF NEVADA

RENO, NEVADA

1964

PART I

TABLE OF CONTENTS

rage
Summary and Conclusions
Introduction
Purpose and scope of investigation
Site requirements
Project organization
Acknowledgements
Methods of Investigation
Access to site
Aerial photographs and base maps
Geology
Geophysics
Hydrogeology and hydrology
Diamond drilling
Report preparation
Geographic Setting
Location
Cuiture
Geology
Geology of the Sand Springs Range
Introduction
Rock Types
Mesozoic (?) metamorphic rocks
Cretaceous granitic body
Aplite-pegmatite dikes
Andesite dikes
Rhyolite dikes
Intrusive breccia
Quaternary-Tertiary volcanic rocks 30
Quaternary-Tertiary sedimentary deposits 30
Structures
Folding
Faults
Northwest-trending faults
Northeast-trending faults
Thrust fault
Joints
Fracture cleavage
Other faults, fracture cleavage, and joints 34
Alteration
Ore Deposits
Tungsten contact metasomatic deposits
Silver-gold veins
Quartz veins

I	Page
Geology of Area B, including trenched area	36
Surface geology	36
Subsurface geology	38
Geophysics	40
Gravity survey	40
Introduction	40
Field measurements	40
Data reduction	41
Gravi y map and profiles	42
Qualitative interpretation	43
Quantitative interpretation	44
Aeromagnetic survey	46
Introduction	46
Interpretation	47
Refraction survey	49
Introduction	49
Equipment and drilling	49
Profiles	50
Physical properties of the drill core	54
Thermal conductivity	54
Modulus of elasticity	55
Permeability	55
General observations	58
Hydrogeology and Hydrology	60
Nature of the problem	60
Summary of drilling and testing program	60
Hydrogeology	64
Geology of the valley fill	65
Fairview Valley	65
Fourmile and Eightmile Flats	67
Hydrologic changes induced by earthquakes	71
Occurrence of round water	
Geohydrology	72
Hydraulic properties	72
Pumping tests in Fairview Valley	74
Pumping tests in Fourmile Flat	78
Hydrologic tests at proposed Ground-Zero	78
Movement	83
Chemistry and temperature of the water	85
Probability and extent of contamination	87
References	89
	09
Appendices Appendix A - Log of Diamond Drill Hole ECH-A	0.1
··	
Appendix s - Log of Diamond Drill Hole ECH-D	
Explanation for Appendices C, D, E, and F	
Appendix C - Lithologic Log of Test Hole HS-1	
Appendix D - Lithologic Log of Test Hole H-2	
Appendix E - Lithologic Log of Test Hole H-3	
Appendix F - Lichologic Log of Test Hole H-4	
Appendix G - Chemical Analyses of Well Water	3.40

ILLUSTRATIONS

		Page
	Figures	
1	Index was to supposed Chool site - Cond Comings Dayso Noveds	12
	Index map to proposed Shoal site - Sand Springs Range, Nevada Fallon cumulative precipitation departure graph	
	Time-distance curves, spread 3, Profile I	
	Time-distance curves, Profile II	
	Time-distance curves, Frontie II	
		غد
0.	Stress-strain hysteresis load curves, core segment of	5.4
7	granite at 512 feet in Core Hole ECH-D	56
/•	Stress-strain hysteresis load curves, core segment of	56
0	granite at 995 feet in Core Hole ECH-D	90
٥.	Stress-strain hysteresis load curves, core segment of granite at 1,422 feet in Core Hole ECH-D	5 7
Ω	·	37
9.	Stress-strain hysteresis load curves, core segment of granite at 2,003 feet in Core Hole ECH-D	57
10		
	Hydrologic index map	
	Geology of the valley fill	
	Stratigraphic section of alluvial fill deposits	
	Pumping test data curve for the upper aquifer in Fair iew Valley.	
	Pumping test data curve for the lower quifer in Fairview Valley.	
	Pumping test data curve for Well 17 in Fairv: /alley	
	Pumping test data curve for Test Hole H-2 in Fourmile Flat	
1/.	Recovery curves for Core Hole ECH-D	96
	Tables	
	rables	
1.	Annual and monthly average precipitation in inches,	
	Fallon Experiment Station	21
2.	Young's Modulus, thermal conductivity, and permeability of	
	granite	59
3.	Water wells and springs inventoried for Project Shoal	29
٠.	Churchill County, Nevada	62
4.	Summary of transmissibility, apparent permeability and	U.
• •	storage coefficients determined by pumping tests	75
5.	Temperatures (°F) of water from wells	
٠,	respectation (1) or water from wellow	0,7
	Plates	
	(In accompanying box)	
	(a. a.a. (a.a.)	
1.	Semicontr lled photo mosaic Area B (Ground Zero Area).	
	Semicontrolled photo mosaic Area A (Sand Springs Range and environ	s).
	Reconnaissance geologic map and sections, Sands Springs Range.	,
	Geologic map and section Area B (Ground Zero Area).	
	Detailed geologic map and section Area B (Ground Zero Area).	
	Gravity map and profiles Sand Springs Range and vicinity.	
	Aeromagnetic map of Area A (Sand Springs Range and environs).	
	Ceophysical logs and geological log of Diamond Drill Hole ECH-D.	
•	The book and the same data and at a remaining a part of the same at	

SUMMARY AND CONCLUSIONS by S. E. Jerome and G. B. Maxey

To help evaluate the Sand Springs Range as a site for the Atomic Energy Commission's underground nuclear Sheal Event, the University of Nevada with the aid of subcontractors and Atomic Energy Commission support groups (Holmes and Narver, Inc., and Reynolds Electrical and Engineering Co., Inc.), completed in September 1962 an exploration program begun late in November, 1961. Elements of this program included bulldozer work, engineering control, aerial photography, preparation of photomosaics and topographic maps, geological mapping at three different scales, mineralogical studies, age determinations, diamond drilling of two test holes in granite, a gravity survey, an aeromagnetic survey, a refraction survey, certain physical tests on the core, study of the hydrology of the Range and the surrounding alluvium, drilling and study of four hydrological test holes in the alluvium, and study of hydrological conditions of the two holes in granite.

The northerly-elongated Sand Springs Range is cored by a medium- to coarse-grained, locally porphyritic, Cretaceous granitic body (granite-granodiorite), almost batholithic in size. On the north this intrusive is flanked by metamorphic rocks of probable Mesozoic and older age, and by Quaternary-Tertiary volcanic rocks. Metamorphic rocks in intrusive contact with the granite on the southwest are in turn lapped by Quaternary-Tertiary volcanics and alluvium. Fairview Valley lies on the east; geological and geophysical evidence indicates this is a complexly down-faulted block. The west-central part of the intrusive locally is overlapped by basalt flows which protrude eastward from the Cocoon Mountains. On the northwest is Fourmile Flat, which geological and geophysical evidence suggests to be a pediment floored mostly by granite and locally by metamorphic rock, and on which alluvial veneer gradually thickens westward.

The granite mass is broken by steeply dipping faults that strike predominantly N. $50^{\circ}-60^{\circ}$ W. and N. 30° E., and by joints, the best developed of which also strike N. $50^{\circ}-60^{\circ}$ W. and dip steeply. Closely spaced fracture cleavage planes that trend N. 30° E. and dip steeply, are prominent throughout the Range.

Aplite pegmatite dikes are abundant in an elongate zone on the north-west side of the granite. This zone curves southeast through the west central part of the Range and intersects the granite-metamorphic rock contact to the south. These relatively narrow dikes are generally chaotic in strike and dip in the central part of the zone but commonly are oriented by the northwest joint set on the fringes of the zone. This is especially true of the Ground-Zero area. A mast of intrusive breccia that somewhat resembles aplite, but which probably is more closely related to younger rhyolite dikes, occurs on the northeast side of the Range.

The northwest-trending faults and joints in the north half of the Range often are occupied by swarms of steeply dipping andesite and rhyolite dikes that rarely exceed 50 feet in width. The faults, particularly where the rhyolite dikes predominate, commonly have wide bleached and iron-stained

bands. To the south, dikes are much less abundant and have northeast, east, and northwest orientations.

The gravity survey, designed to investigate the flanks of the Sand Springs Range and neighboring valleys, show an expected gravity high over the mountains and lows over the valleys. The westward displacement of the high is attributed to metamorphics which could extend northwest under the alluvium of Fourmile Flat and possibly through the position of hydrological test hole H-3. The eastern side of the Range is bounded by a series of northwest— and northeast—trending faults of large displacement. A gravity nose extending into Fairview Valley south of Lucky Boy Canyon, marked also by a small aeromagnetic high, is interpreted as being produced by a shallow buried horst capped by metamorphics. No faults of large offset are evident from gravity data on the northwest side; there appears instead to be a rather featureless bedrock surface that dips westward at a low angle.

Using a quantitative approach based on an assumed density contrast of 0.5 g/cc, depth to "bedrock" in Fairview Valley is calculated at 5,800 feet; this is in good agreement with the depth obtained from aeromagnetic data. The depression apparently is a combination of step-faulting and downwarping. The western side of the Range may be bounded by a normal fault with a displacement of about 2,000 feet-rart topographic and part stratigraphic. A section of metamorphic rocks is interpreted to extend from outcrops on the northwest end of the Range southward through test hole H-3. This either could be a xenolith in granite, or could represent the western contact of the main intrusive. The fill in Fourmile Flat appears to be 1,000 to 1,300 feet thick and apparently does not include thick basalt flows. If metamorphic rocks are present, thickness of the fill actually may exceed 2,000 feet, more in keeping with a thickness of 2,500 feet calculated from aeromagnetic data.

The aeromagnetic data help in the interpretation of gravity data as noted. Most of the major rock units described above can be identified by a characteristic grain on the aeromagnetic map. The limits of the surface exposures of the granite can easily be seen. The northern contact of the granite with the metamorphics is marked for its entire length by a prominent magnetic low which probably is due to the geometric effect as well as to contact effects, hydrothermal alteration, etc. On the south the granite pattern abuts the large magnetic high over the metamorphics. It is impossible to determine magnetometrically the extent of the granite north and south of its surface exposures because of the masking effect of overlying rocks. The presence of faults in Fairview Valley, away from the Range front, is based in part on small magnetic anomalies.

Refraction work was designed to augment gravity and aeromagnetic data. Crude seismic tests on granite in the Ground-Zero area produced low velocities, attributed to weathering and relatively open fracture cleavage. The first refraction profile confirms the thinness of alluvium in Fourmile Flat, and the velocities obtained suggest either weathered granite or metamorphics under unconsolidated alluvium. The second profile indicates a high velocity medium near test hole H-3 at a depth of 196 feet and dipping gently west, this medium is interpreted as 114 feet of metamorphic rock

overlying granite, an interpretation which conforms well with gravity and aeromagnetic results. The third profile in Fairview Valley suggests compacted fill, the position of the water table, and depths to granite in excess of 2,000 feet for the line covered.

Water occurs at the surface in a few places and at varying depths underground throughout the area. In nearly all instances ground water is found shallower in the valleys and deeper in the mountains, although a few eeps and springs in the Sand Springs and Stillwater Ranges and on Fairview-Slate Mountain attest to the presence of some shallow, probably small, bodies of perched or otherwise trapped water. Evidence from drilling in the Sand Springs Range granite is essentially inconclusive regarding the water-bearing characteristics of these rocks, although it has been established that some water does occur in the granite. The consolidated rocks act as geohydrologic barriers and neither store nor transmit appreciable quantities of water-appreciable, at least, in relation to any probable contamination hazard that might result from the Shoal experiment. Therefore, emphasis in hydrogeologic study has been placed on the valley fill, because these sediments do contain and transmit appreciable quantities of water and form the reservoirs from which water supplies are withdrawn.

Near the Sand Springs Range the fill of Fairview Valley, and the valley of Fourmile and Eightmile Flats, consists of alluvial fan or apron sediments which farther down the alluvial slopes are cut by lake terraces and are overlain by lacustrine sand and silt. The alluvial and lacustrine deposits are cut by stream channels filled, in most instances, with varying but small thicknesses of stream alluvium. Thus, the upper parts of the alluvial slopes and lake terraces are composed of relatively permeable sediments, while the valley fill is composed of both interbedded coarser materials which form aquifers below a depth of about 300 feet, and finer materials that form aquicludes. Playa deposits in the central low parts of the valleys contain a much higher proportion of fine materials, primarily fine silt with a little clay.

In Fairview Valley, ground water occurs at depths varying from over 300 feet, high on the alluvial slope, to about 225 feet near the valley center. Hydraulic gradients of the piezometric surface are low, on the order of 3 feet per mile, and the water moves with an apparent velocity of between 0.03 and 0.07 foot per day. It is doubtful that average velocities exceed 25 feet per year. Pumping tests indicate a range of the coefficient of transmissibility from about 5,000 to 17,000 gallons per day per foot, and a range of the coefficient of storage from about 2 x 10^{-4} to 3.5×10^{-4} .

In Fourmile Flat, ground water occurs at depths ranging from over 300 feet, high on the alluvial slopes, to a few feet or less in the valley bottom. Here the playa area is a "point sink" with water moving toward the playa from all directions to be discharged eventually by evapotranspiration. The piezometric surface is nearly flat, that is, gradients from all directions toward the point of discharge are extremely low, ranging from about 1.46 feet per mile to essentially horizontal. Estimates f

velocity range from 0.02 feet per day to 0.04 feet per day, or on the order of 16 feet per year. The estimated coefficient of transmissibility of the granite, which acts as an aquifer high on the flank of the Range, is less than 200 gallons a day per foot. The coefficient of transmissibility of the alluvial materials near the east margin of the playa is about 76,000 gallons a day per foot.

Chemical data verify the conclusions regarding the gradients mentioned above. They also indicate that little if any recharge to the alluvial fill occurs on the west side of the Range. Preliminary study of distribution coefficients of materials determined in other areas such as the Nevada Test Site and Hanford, indicates that both the granite in the Sand Springs Range and the alluvial fill in adjoining valleys, would rapidly fix the radionuclides resulting from the proposed test shot. It is presently deemed safe to say that under ordinary conditions of underground movement of water at the estimated gradients in the Range, the radionuclides will not travel beyond the Range front.

If these estimates and this conclusion are in error and radionuclides should be carried by ground water into the alluvial fill, they will be fixed within a short distance of the Range front. This conclusion is substantiated by the following:

- 1. The gradients in the valley fill are very low, and the more or less uniform permeability of any section of the alluvial fill precludes anomalously rapid movement. Velocities calculated from the known gradients and permeabilities are low, on the order of three feet per mile in Fairview Valley and 1.46 feet per mile per year in Fourmile Flat.
- 2. The distribution coefficient of the alluvium is certainly higher than that of the granite, for the alluvium is the weathered product of the granite composed of discrete particles with much more exposed surface area.

The conclusions given above are based on the assumption that the shot will be wholly contained.

The granite within 1,000 feet of Ground-Zero, though jointed, cleaved, and faulted, is relatively unaltered and free of dikes. Faults recognized at surface also were identified in NX diamond drill hole ECH-A (N. 60° W., -45°, 1,898 feet). The upper portion of 6-inch diamond drill hole ECH-D (vertical, 2,017 feet) penetrated jointed and cleaved, relatively fresh granite, but at 1,440 feat a fault zone was encountered that extends to 1,675 feet. This zone is about 75 feet wide, dips about 70°, and probably is the lownward extension either of a northeast fault zone exposed west of ECH-D, or an east-west fault zone north of ECH-D (exposed by additional trenching in August 1962), or a combination of both. Nothing logged in either of the two holes suggests that either a flat thrust or a dike swarm is present at the proposed shot depth.

Thermal conductivity, elasticity, and permeability tests, and petrographic examination of core selected from 5.2, 994, 1,422, and 2,004 feet in ECH-D indicate, except for the fault zone, that the granite has essentially the same characteristics throughout the hole. Results from the tests are comparable with those reported in the literature for similar material. Results of the logs run in August 1962, by Schlumberger Well Surveying Corp. show excellent correlation with the lithologic logs.

Recovery tests and other observations made during the drilling of ECH-D indicate that some water occurs in the granite below a depth of about 1,086 feet. Little more can be said of the total hydrological characteristics of the Ground-Zero site.

If the preferred shot depth continues to be 1,500 feet, some constructional difficulties should be anticipated in the fault zone between 1,440 feet and 1,500 feet. These difficulties will be aggravated by water from 1,086 feet down to the emplacement point. If the depth is raised to 1,200 feet or less, only local and minor trouble will be caused by joint and fracture cleavage planes. At a depth of 1,200 feet the shot apparently will be about 114 feet under a normal or perched water table.

Although the immediate vicinity of Ground-Zero is one of the least fractured and altered parts of the Sand Springs Range, there are no extensive blocks of granite in which shock waves could travel without encountering fault surfaces. The pattern and density of faults and joints around the shot point, and the increasing number of dikes of various types away from that point may complicate the arrangement of seismographic stations. It is not believed that conditions could be improved much by moving the emplacement hole some distance from ECH-D; if such a move is desired, at least two additional small diameter holes should be drilled to establish ground characteristics of the new shot point.

With some reservation because of our limited knowledge of all requirements for the experiment, we conclude from exploration results and consideration of those safety factors related to geology, that the Sand Springs Range is suitable for the Shoal Event. The site is somewhat more complicated by joints, cleavage, faults, dikes, and water than was realized when it was selected for more detailed study, but the exploration results should not be surprising for an area so active seismically. "Others" must decide whether or not the complications really detract from the acceptability of the site.

INTRODUCTION by S. E. Jerome

Purpose and Scope of Investigation

The Shoal Event is a part of Project Shade of the Vela-Uniform program sponsored jointly by the Department of Defense and the Atomic Energy Commission. Its purpose is to improve our knowledge of the characteristics of seismic waves generated by man-made explosions, especially as related to the detection and identification of underground nuclear explosions.

Prior to the test reasonable assurance had to be given that rock conditions are satisfactory for the evaluation of test results; that no shock damage would result to surface structures, wells, or mine openings; and that no short or long term safety or health hazards would be generated by the explosion. This report contains the results of the geological, geophysical, and hydrological investigations that contributed to the evaluation of these conditions.

In preparing this report the writers have drawn freely from all information on the Shoal site readily available to them. Reports consulted are listed under References. A cardboard box of folded Plates accompanies this report.

Site Requirements

As a result of reconnaissance surveys of possible sites outside of California for the Shoal Event, a committee consisting of representatives of the U. S. Atomic Energy Commission, the U. S. Geological Survey, and the engineering firm of Holmes & Narver, Inc. determined that the Sand Springs Range, Churchill County, Nevada (see Figure 1) came nearest to meeting the following requirements:

- 1. Geologic medium to be tuff or granite in an area of simple geologic structure.
- 2. Relief to vary not more than 1,000 feet within a two-mile radius from Ground-Zero.
- 3. Emplacement depth to be 1,500 feet if in granite, or 1,350 feet if in tuff.
- 4. Site to be in a currently active seismic area with recent history of strong shallow-focus earthquakes.
- 5. Several granite outcrops to be located within a radius of 1,500 feet from the center of the site. Location of shot within chosen seismic area and depth of overburden are not of critical importance.
- 6. Technical operations to include a central working area around Ground-Zero, extending outward for a radial distance of 1/2 mile. Additional areas outside of the central areas to be available for strong motion studies.
- 7. Strong motion measurements and intermediate range measurements to be similar to those programm or Lollipop. Approximately 40 temporary seism graphic stations to be used in linear and azimuthal patterns at distances ranging from 200 to 4,000 kilometers.

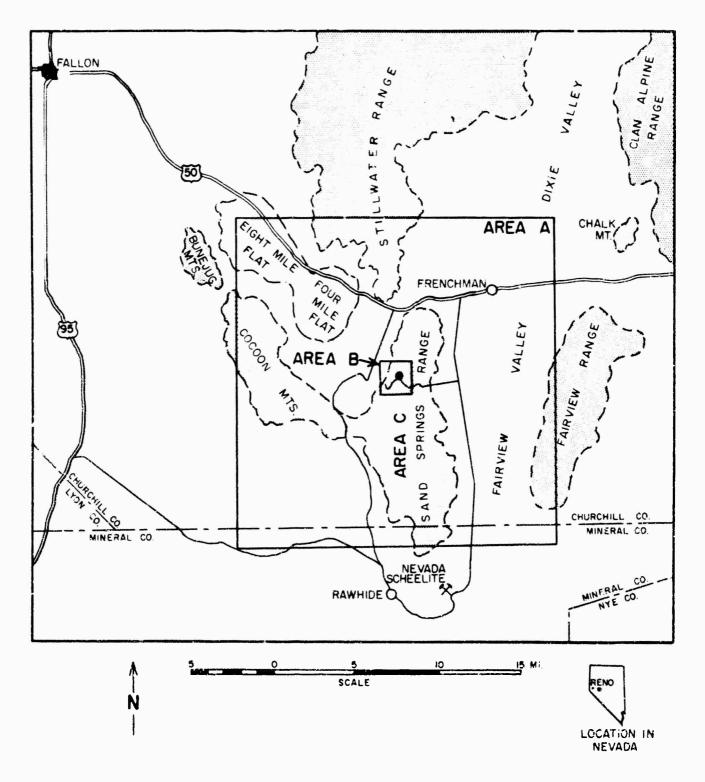


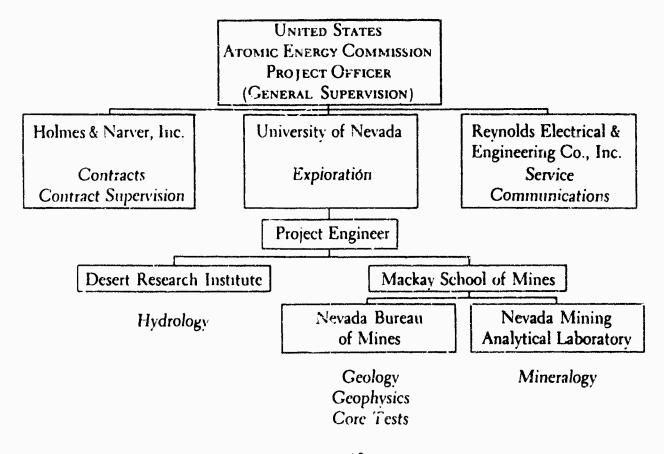
Figure 1. Index map to proposed Shoal site-Sand Springs Range, Nevada

- 8. Two half-acre areas, separated by a distance of 1/4 mile, to be available for each off-site seismographic station. Bedrock outcrops to be available in one area of each pair, for use as seismographic vaults. The other area to provide for a recording snelter, generator, and vehicle storage.
- 9. The site to le in an area of low population and several miles removed from mar-made structures.

Project Organization

In July 1961 preliminary discussions between representatives of the Atomic Energy Commission and the Mackay School of Mines, University of Nevada, led to a request from Mr. James E. Reeves, currently manager of Nevada Operations, U. S. Atomic Energy Commission, that the Mackay School of Mines submit a proposal covering the geological exploration phase of work involved in determining the suitability of the Sand Springs site. A preliminary proposal made in August 1961 was followed in November 1961 by a modified final one, accepted by the Atomic Energy Commission. This included geological, geophysical, and hydrological studies to be conducted by Mackay School of lines and Desert Research Institute personnel over an estimated period of 37 weeks and involving an expenditure slightly in excess of \$188,500. The program was accivated on November 16, 1961 and completed in September 1962.

The general organizational arrangement of participating agencies and University groups cooperating during the exploration phase of the Shoal Event was as follows:



The University of Nevada's exploration program was conducted with the endorsement and support of Dr. Charles J. Armstrong, University President, Dr. Vernon E. Scheid, Dean of the Mackay School of Mines and Director of the Nevada Bureau of Mines and Nevada Mining Analytical Laboratory, and Professor Wendell A. Mordy, Director of the Desert Research Institute.

The work was under the overall supervision of Dr. Stanle E. Jerome, Associate Director of the Nevada Bureau of Mines and Nevada Mining Analytical Laboratory. Dr. George B. Maxey and associates of the Desert Research Institute (DRI) were responsible for hydrologic aspects of the program. Nevada Bureau of Mines (NBM) and Nevada Mining Analytical Laboratory (NMAL) personnel handled all other phases of the work in accordance with their fields of specialization.

ACKNOWLEDGMENTS

Members of the University staff connected with the Shoal project wish to express their appreciation to personnel of the Atomic Energy Commission, Holmes & Narver, Inc., and Reynolds Electrical and Engineering Co., Inc., for the cooperative and congenial atmosphere in which the exploration work was conducted.

METHODS OF INVESTIGATION by S. E. Jerome

Access to Site

To expedite the exploration and subsequent work in the vicinity of the test site, 24 miles of roadway either were newly built or were improved from existing roads. A new road approximately 8 miles long was bulldozed south from U. S. Highway 50 along the west side of the range to a junction with an old, infrequently used road connecting Highway 50 with Rawhide. (See Figure 1.) This latter road was then improved by grader for an additional 11 miles southward to its junction with the Rawhide-Schurz road.

A five-mile road also was built on the east side of the Rarge to serve as an access to the tentative Ground-Zero site and the microwave radio relay station on a peak to the west. This road proceeds westward from a point on the county road serving the Nevada Scheelite mine, and for the last three miles follows one of the few canyons in the central part of the Range that does not contain formidable road-building obstacles.

Road work and subsequent bulldozer trenches were laid out by R. Horton (NBM) assisted by J. Schilling (NBM). The jobs were let to a Tallon contractor by Holmes & Narver, Inc. who supervised his activities.

Aerial Photographs and Base Maps

In November 1961 the only available topographic map covering the region selected for Shoal exploration was the Army Map Service 1:250,000 scale Reno sheet, based on 1:60,000 aerial photography. Since this material obviously was inadequate for detailed planning and mapping purposes, specifications were completed by J. Gimlett (NBM) for aerial photography and topographic map coverage. A contract under his supervision was let to Mark Hurd Aerial Surveys, Inc., 5760 Dawson Ave., Goleta, California. A 400-square-mile block (Area A), centered on tentative Ground-Zero, was covered by 1:31,680 photography. For topographic mapping purposes photographs also were taken of two other areas within this block, Area B at 1:12,000 and Area C at 1:52,000. (See Figure 1.) Items based on this photography which can be ordered directly from Mark Hurd include:

- 1. 112 contact prints at about 1:31,680 of Area A; 25 contact prints at about 1:12,000 covering the proposed site, Area B; and 15 contact prints at about 1:52,000 of the Sand Springs Range, Area C. Enlargements of all of the above also can be ordered.
- 2. Photo-index maps to the above photography.
- 3. Semicontrolled photomosaic of Area A at about 1:31,680. Plate 2. (A reduction of this photomosaic to about 1:62,500 also is available.)
- 4. Semicontrolled photomosaic of Area B at about 1:6,000. Plate 1.

- 5. Topographic map of Sand Springs Range at 1:31,680. Contour interval 40 feet. Used as a base map for presenting reconnaissance geology. Plate 3.
- 6. Topographic map of Area B, four-square-mile block centered on tentative Ground-Zero, at 1:6,000. Contour interval 5 feet. Used as a base map for presenting detailed geology. Plate 4.
- 7. A portion of the 1:6,000 topographic map has been enlarged to 1:2,400 and used in Plate 5 to show structural details of the granite in the vicinity of tentative Ground-Zero.

To prepare the topographic maps from photography, Mark Hurd Aerial Surveys, Inc. used U. S. Coast and Geodetic Survey coordinates and elevations supplemented by stations triangulated and levelled by Sprout Engineers, Inc., operating under contract to Holmes & Narver, Inc. and supervised by R. Horton and J. Gimlett. Prior to photography, all control points were panelled by Sprout Engineers, Inc., aided in part by helicopters from the Naval Auxiliary Air Station at Fallon.

Surveying, panelling, and flying for photography were hampered by unusually heavy snow storms. The season in which the job was initiated was not conducive to high-quality results from aerial photography. While some of the photographs and photomosaics are rather striking because of long, black shadows on north-facing slopes, such shadows made portions of some photographs almost useless in areas of extreme relief for both topographic and geologic mapping.

Geology

Geological reconnaissance of about 55 square mile in the Sand Springs Range was conducted as weather permitted between the end of January and the first of May by NBM personnel, <u>L. Beal</u>, <u>S. Jerome</u>, I. Lutsey, R. Olson, and <u>J. Schilling</u>. (Those with names underlined here, and subsequently, devoted the most continuous effort to completing a particular phase of work. If the burden was equal, underlines are omitted.) Snow storms interrupted mapping on several occasions. The 1:31,680 aerial photographs, supplemented in part by enlargements to 1:12,000 were used as mapping bases. Results were compiled on Mark Hurd's 1:31,680 topographic map and are presented on Plate 3.

Detailed mapping of Area B was completed in March by Messrs. Beal, Jerome, and Schilling, Photo-enlargements at 1:6,000 were used as bases, and the results compiled to Mark Hurd's 1:6,000 topographic sheet. (See Plate 4.)

It was evident that outcrops in the vicinity of Ground-Zero were too scattered to permit reasonable appraisal of rock conditions in advance of deep exploratory drilling. Bulldozer trenches supplemented by short diamond drill holes were proposed. After access was gained to Area B, R. Horton laid out roughly north-south and east-west trench lines; these were stripped by grader and bulldozer. (See Plates 1, 4, and 5.) In the hope of eliminating many short diamond drill holes, alternate north-south trenches and all

east-west trenches subsequently were ripped by heavy bulldozers. Owing to closely spaced fracture cleavage planes in the granite, ripping proved to be so effective a method for disclosing structure and rock types that the projected drilling of short diamond drill holes was eliminated.

Trenches totaled about 12 miles. Using a rough layout map prepared by Sprout Engineers, most of the trenches were mapped at 1:2,400 scale; this work was supplemented by a number of mapping traverses in adjacent areas, totaling 6,400 feet, which contributed substantially to the study. Results presented on Plate 5 were obtained by Messrs. Beal, Horton, Jerome, Lutsey, Olson and Schilling. Early completion of this work in December and January permitted the initiation of exploratory diamond drilling and saved the job from undue weather delays. Subsequently, in August 1962 one and three-quarter miles of additional trenching and ripping were done to help clarify fault details in the vicinity of Ground-Zero. Mapping was completed by L. Agenbroad and S. Jerome.

Ground observations were supplemented by two flights over the area in June 1962, when a number of oblique aerial photographs were taken. Fifty-eight thin sections were prepared by J. Murphy (NBM), and examined and described in detail by A. von Volborth (NMAL). Results have been condensed and are incorporated in the geology section of this report. Four age determinations were made by Geochron Laboratories on material prepared by J. Murphy.

The geological field work was greatly expedited by the use of four Tote Gotes purchased expressly for this job. These amazingly rugged "motor scooters" are particularly adapted to this terrain. Their use helped to compensate for the difficulties and delays in mapping caused by adverse weather; without them the job could not have been completed in the allotted time.

Geophysics

Approximately 84 miles of line for gravity observations were surveyed and levelled by Sprout Engineers, Inc., operating under contract to Holmes & Narver, Inc. The layout of lines and observation stations is illustrated on Plate 6. Field observations were made by Messrs. J. <u>Gimlett</u>, R. <u>Horton</u>, and J. Schilling, using a Worden gravity meter rented from Texas Instruments, Inc. Data reduction and interpretations were completed by J. Gimlett.

Some seismic velocity tests were made in the vicinity of Ground-Zero by Messrs. Gimlett and Horton, using Dynametric Inc. equipment. Seismic refraction surveys were planned and executed by J. Gimlett, assisted in the field by J. Soske, of Stanford University, and R. Horton. Calculations and interpretations are by J. Gimlett. Shot holes for the placement of dynamite were drilled by Sprout Engineers, Inc., under arrangement with the University. Lines are shown on Plate 6.

Fairchild Aerial Surveys, Inc. was low bidder on the aeromagnetic survey of Area A which was planned and interpreted by J. Gimlett. To lay out flight lines Fairchild used Mark Hurd's 1:31,680 semicontrolled photomosaic. Lines are oriented east-west and are spaced half-a-mile apart. Average flight

elevation was specified at 500 feet above mean terrain, a feat relatively easy to accomplish over the major valleys but difficult to impossible over the ranges. Fairchild's contour map, printed as an overlay on the photomosaic, is included as Plate 7.

Hydrogeology and Hydrology

Hydrologic work was begun in February 1962 and continues to the present time. (December 1964)

The four hydrologic test holes listed below were located by G. Maxey and drilled by F.11 & Hill Drilling Co. under contract to Holmes & Narver, Inc.

Hole No.	Location	Depth	Material at Bottom
HS-1	Fairview Valley	699 '	Alluvium
H-4	Fairview Valley	935'	Alluvium
H-2	Fourmile Flat	780 '	Alluvium
H-3	Fourmile Flat	470 *	Granite

These holes were logged and tested to help determine the lithology, position, and hydraulic characteristics of the aquifers and other strata, and the quality, mode of occurrence, and movement of ground water in Fourmile Flat and Fairview Valley. Gamma ray, neutron, and temperature logs were conducted by McCullough Tool Co. in H-4 and H-3. Well logs are included herewith as Appendices C, D, E, and F. The two wells at Frenchman's Station were tested by pumping.

Approximately 38 water points (wells, springs, intermittent streams) have been inventoried within a 15-mile radius of Ground-Zero. As integral parts of the inventory, water samples have been collected and analyzed by Abbott and Hanks for chemical constituents and by the U. S. Public Health Service for radiological constituents; water levels have been measured; depths and other dimensions of the wells have been recorded; discharges of springs and surface streams have been measured; and the uses to which the water is put have been determined. Other factors which might affect the contamination problem, such as topographic and geologic setting, have been observed and recorded. A geological reconnaissance of the valley fill has been completed, and has been supplemented by more detailed study. Results are presented in Part II - Section B.

DRI personnel P. Domenico, G. Maxey, G. Scudder, and D. Stephenson been responsible for the hydrologic work.

Diamond Drilling

Two exploratory holes were diamond-drilled to test ground conditions in with near Ground-Zero. The first, NX hole ECH-A, was directed N. 60° W., with need -45°, and bottomed at 1,898 feet. It was contracted to Sprague and convoid by Holmes & Narver, Inc. The latter organization also contracted the Core Drilling Inc. for ECH-D, a six-inch vertical hole bottomed at

2,017 feet, within 50 feet of Ground-Zero. All directional surveying was done under the supervision of Holmes & Narver, Inc.

Although NBM personnel L. Agenbroad, L. Beal, "Horton, S. Jerome, I. Lutsey, H. Mossman, and R. Wilson contributed to logging the core, J. Schilling was primarily responsible for this work and for reporting the results.

The thermal conductivity and elastic properties of core from ECH-D were determined and interpreted by R. Horton; the permeability was determined by Core Labs, Inc. DRI personnel P. Domenico, <u>G. Maxey</u>, <u>G. Scudder</u> and <u>D</u>. Stephenson were responsible for hydrologic work on the diamond drill holes.

Report Preparation

All NBM and DRI personnel so far cited, contributed to the assembly, analysis, and reporting of results in Part I. The finished drafting and cartography are by NBM personnel B. Webb, R. Wilson, and R. Paul. Color separations for the geologic maps were made by B. Webb. J. Schilling coordinated map and report preparation for Part I. S. Jerome coordinated the final report. I. Lutsey and L. Rollin handled editorial problems.

This part and subsequent ones were typed under the supervision of H. Mossman (NBM) and C. Menzel (DRI). All plates were printed by Stark-Rath Printing and Publishing Co., San Francisco, California.

GEOGRAPHIC SETTING

by John H. Schilling

LOCATION

The Sand Springs Range, a north-trending mountain range approximately 20 miles in length and 5 miles in maximum width, is mainly in Churchill County, Nevada, about 28 miles southeast of Fallon, Nevada, the nearest community. (See Figure 1 and Plate 2.) It is bounded on the east by Fairview Valley and on the west by Fourmile Flat. The Range is separated from its northward extension, the Stillwater Range, by a low pass. To the south the mountain mass broadens into rolling hills that blend into the Cocoon Mountains on the west and Slate Mountain to the southeast.

U. S. Highway 50 crosses the pass at the north end of the Range. A paved road extends south from Highway 50 along the east flank of the range to the Nevada Scheelite mine and camp. A graded track along the west flank of the range extends south to the ghost town of Rawhide, which also can be reached by a graded road from the Nevada Scheelite camp. A paved road (closed to the public) from the Nevada Scheelite road provides access to the roal site.

PHYS IOGRAPHY

The Sand springs Range is in the Great Basin part of the Basin and Range Fhysiographic Province. Much of the northern half of the range is rolling plateau with low relative relief, bordered on the east and west by steep scarps. This platean is 1,000 to 1,300 feet above adjacent valley floors with maximum elevations that barely exceed 5,600 feet. Here the Range is asymmetric in that numerous long, broad canyons lead gradually up from the eastern side, but those on the western side are very short, narrow, and steep-walled by comparison. In contrast the southern half of the Range is dominated by a northwest-trending ridge whose summits average between 0,600 and 6,800 feet. Here the east flank is steep while the west side has a more gentle slope.

Fairview Valley lies east of the Sand Springs Range and is bounded by the Clan Alpine Range and Fairview and Slate Mountains on the east. The valley is about thirty miles long, rising in the "Y" formed by the junction of the Sand Springs Range and Slate Mountain, and extending northward to a relatively narrow constriction and low divide about five miles wide, between the Stillwater and Clan Alpine Ranges. The valley floor slopes northward from 5,500 feet at the south end to about 3,900 feet at Labou Flat, a playa just south of U. S. Highway 50, which is the low point in the valley. The low divide at the north limit of the valley separates it from Dixie Valley into which a stream rising far to the east flows.

Fourmile Flat is a playa on the west side of the Sand Springs Range. It is continuous with Eightmile Flat which extends northwestward and which is slightly up gradient from it. These two areas form one large alkali

flat between the Stillwater Range to the north, the Bunejug and Cocoon Mountains to the south, and the Sand Springs Range. Fourmile Flat, the lowest part of the alkali flat, is also the lowest depression along the east side of the Fallon area and approximates the altitudes of Carson Sink to the north and Carson Lake to the west. Thus, some surface runoff from a broad area east of Fallon flows through Eightmile Flat into Fourmile Flat. Conditions of topography and relief are essentially the same as in Fairview Valley.

Apart from drainage and irrigation canals in the Fallon area, and small streams in the mountains to the north, perennial streams or other perennial water bodies are unknown within or near the area. There are only a few small, usually intermittent springs, as well as intermittent playa lakes on Labou and Fourmile Flats.

CLIMATE

The Band Springs Range and environs are a typical Great Basin arid region with about 5 inches annual precipitation in the valleys and about 12 inches at the highest elevations, according to the studies by Hardman (1949). Records of precipitation at the Fallon Experiment Station, about 35 miles west of the range are given in Figure 2 showing the cumulative departure from running average monthly precipitation values for the 53-year period from 1909 through 1961, and in Table 1 showing mean aonthly and annual precipitation values as reported in the 1961 annual summary by the U. S. Weather Bureau (1961).

TABLE 1

Annual and Monthly Average Precipitation, In Inches,
Fallon Experiment Station

Jan.	Feb.	Mar.	Apr.	May	Jun.
.57		.55	.51	.ól	.42
July	Aug.	Sep.	Oct.	Nov.	Dec.
.17	.12	.20	.50	.35	.ó8

Year 5.34

July, August, and September are the driest months and late winter and early spring is the wettest period. Fallon receives about 10 inches of snowfall annually, most of it during the winter and early spring. The total precipitation and snowfall may be expected to be somewhat higher in the Sand Springs Range than at Fallon. The absence of trees in the Range is testimony to the arid conditions. Figure 2 shows that the amount of yearly precipitation fluctuates considerably and that longer cycles of wet and dry periods occur. Thus, precipitation increases rather considerably from 1932 until 1947, but since that time has fallen off, and has been below normal.

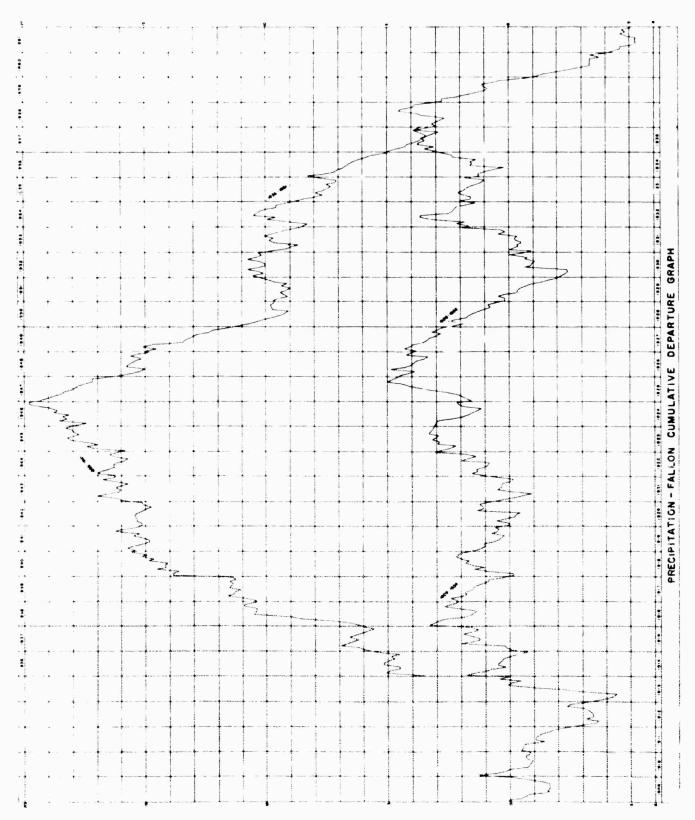


Figure 2. Fallon cumulative precipitation departure graph.

At the Fallon Experiment Station the mean annual temperature is reported to be 50.0 degrees in the 1901 Annual Summary. January is the coldest month and July is the warmest. The average cate for the last killing frost in spring is during the middle of May and the first killing frost occurs in late September, which gives a growing season of about 127 days.

On the basis of fragmentary pan records at Fallen, evaporation is estimated to be about five feet, somewhat more than 10 times the annual precipitation. Wind direction is usually from the west at an average velocity of about 4.5 miles an hour, according to fragmentary records.

Weather station records also are available at Eastgate, about 25 miles east of the site and about 200 feet lower. Because these records have been gept for only 5 years they may not be as representative of the precipitation pattern as those from Fallon. The average annual precipitation recorded at Eastgate is 0.70 inches, a figure that may confirm the like that precipitation increases significantly with altitude.

CULTURE

Within the area chief activities are grazing, limited mining and redining, and dombing practice. Fewer than twenty residents live within 10 ciles of the Sand Springs Range except at the Nevada Scheelite mine near Rewords where probably no more than 50 persons live at any one time. Like the population centers, including Fallon and the Fallon Auxilliary Naval Air Station, are between 25 and 35 miles distant.

GEOLOGY

Geology of the Sand Springs Range by Laurence H. Beal, S. E. Jerome, Ira Lutsey, Richard H. Olson, and John H. Schilling

INTRODUCTION

The Sand Springs Range is made up chiefly of a Creticeous granitic intrusive body bordered on both the north and south by Mesozoic metamorphic rocks. (See Plate 3.) The granitic body also is exposed in the pediment in the southeast corner of the Fourmile Flat basin. Locally both the granite body and metamorphic rocks are overlain by Tertiary and Quaternary volcanic rocks. Numerous aplite-pegmatite dikes cut the granitic body; most of these dikes are concentrated in a zone extending south along the western crest of the range and swinging southeast to the granite-metamorphic contact. Many andesite and rhyolite dikes intrude the granitic body, the metamorphic rocks, and the aplite-pegmatite dikes. Tertiary and Quaternary alluvial and eolian deposits occupy the valleys to the east and west of the range.

Although the range is a north-south trending fault block, north-south faults are rare, the range having been uplifted along a series of northwest-and northeast-trending high-angle faults, which form a sawtoothed pattern in plan. The down-dropped Fairview Valley block to the east contains over 5,000 feet of unconsolidated sediments; in contrast, the Fourmile Flat area to the west is a pediment, thinly veneered with alluvium near the range, the alluvium thickening to about 1,300 feet immediately south of the salt flats.

The structural pattern is remarkably consistent throughout much of the range. A system of steeply dipping faults and joints trending about N. 50° W. cuts the granitic body; most of the dikes are intruded along these structures. A second system of steeply-dipping faults and parallel, closely-spaced fracture cleavage, trending more or less N. 30° E., cuts the granitic body and dikes. Other directions of faulting, jointing, and cleavage are common locally. A gently-north-dipping thrust cuts the metanorphic rocks just south of U. S. Highway 50; there is no evidence of thrusting elsewhere in the range.

ROCK TYPES

Mesozoic(?) Matamorphic Rocks

Mesozoic(?) metamorphic rocks crop out at the servicend of the range and along U. S. Highway 50 at the north end. Although no attempt was made to subdivide the metamorphic rocks, a general idea of the sequence was gained during mapping.

In the north, the metamorphic rocks in the lower plate of the thrust fault include interlayered phyllite, schist, slate, hornfels, and thin, locally marblized limestone beds. The foliated rocks probably are

metamorphosed clastic, pelitic, and calcareous sedimentary rocks and volcanic material. In most cases the foliation parallels the original bedding of the rocks; both generally strike east-west and dip steeply. The upper plate of the thrust is bluish-gray, massive to thick-bedded, recrystallized dolomitic limestone.

In the south, a northwest-trending belt of metamorphic rocks extends across the range. The foliation and original bedding of the rocks in this zone are parallel, both striking northwest and dipping steeply southwest at the northwest end of the belt and vertically at the southeast end. A southern (upper?) unit of gray to white, recrystallized, dolomitic limestone extends from one end of the belt to the other end. Along the Nevada Scheelite road, on the southeast, a middle unit of andesite breccia and flows, and a lower (?) unit of phyllite, slate, and hornfels occur below the limestone unit. These middle and lower (?) units grade or interfinger northwestward into a sequence consisting of inter-layered thin-bedded limestone, schistose graywacke and quartzite, conglomerate, hornfels, phyllite, and slate. Metavolcanic layers are more common in the upper (?) part of this sequence, which is at the same horizon as the andesite breccia and flows to the southeast, than in the lower (?) part which are predominately metasediments.

No comprehensive petrographic examination was made of the various types of metamorphic rocks. Thin sections of the dolomitic limestone from the upper plate of the thrust at the north end of the range show that the limestone is equigranular with 0.05 to 0.3 cm., parallel-oriented grains of calcite and lesser dolomite, and minor margarite mica, cut by dolomite and quartz veinlets. The limestone from the south end of the range is similar, but specimens examined are finely layered, the banding resulting from alternating layers of coarse and fine grains and/or alternating more calcitic and more dolomitic layers.

In thin section, the schist and phyllite are lepidoblastic, or porphyroblastic with a schistose matrix; the hornfels is granoblastic or porphyroblastic with a granoblastic matrix. Of the six thin sections examined, all contain abundant quartz and and alusite, several contain abundant biotite or muscovite, and at least one section contains quartzite and volcanic rock fragments, staurolite, and hornblende.

The metamorphic assemblage is older than any other rocks in the area. It was intruded by the Cretaceous granitic body, and is tentatively dated as Mesozoic, based on its metamorphic and lithologic similarities to Mesozoic rocks elsewhere in Nevada and its age relationship to the granitic body. The extension of at least part of these same metamorphic rocks just to the south of the mapped area in Mineral County has been tentatively correlated with the Triassic Excelsior Formation (Ross, 1961, p. 15-21).

Cretaceous Granitic Body

A Cretaceous granitic body is exposed over much of the Sand Springs Range, and at the southeastern end of Fourmile Flat in the sloping area leading up to the range. Several small exposures occur in "windows" in the volcanic rocks at the north end of the range. This intrusive rock

ranges from granite to granodiorite. The porphyritic granite variety is exposed over much of the range and has been termed "Ground-Zero granite"; the granodiorite variety predominates in the west-central part of the range, to the west of the aplite-pegmatite belt. Along the western escarpment of the range there is a mixed zone of both types.

Both the granite and granodiorite show typical spheroidal weathering. The granodiorite commonly appears to be less weathered than the granite, probably because its finer grain resists rapid weathering.

The Ground-Zero granite is most commonly a porphyritic biotite granite with abundant large microcline phenocrysts up to 2 inches long in a medium-to coarse-grained groundmass of quartz, K-feldspar, plagioclase, varying amounts of small biotite flakes and books, and locally some hornblende. At numerous places scattered throughout the granite, the orthoclase phenocrysts have been segregated into large clusters, lenses, and streaks, some of which have dimensions of over 10 feet; locally the phenocryst segregations comprise up to 75 percent of the rock. Schlieren banding was noted but is not common. Locally the granite is coarsely inequigranular rather than porphyritic. In a few places it shows a rough foliation. In thin section, 30 to 50 percent of the Ground-Zero granite is a hypidiomorphic-granular groundmass of 40 to 60 percent strongly zoned myrmekitic plagioclase (An₁₀₋₂₅), 25 to 40 percent quartz, 5 to 10 percent microcline, 5 to 10 percent biotite, 0 to 1 percent hornblende, and less than 1 percent sphene, apatite, and magnetite.

The granodiorite is an equigranular, medium-grained, normblende granodiorite having much the same mineralogical composition as the Ground-Zero granite, except that hornblende predominates while biotite is rare to abundant. It locally shows well developed gneissic structure. In thin section, the granodiorite is hypidiomorphic-granular and consists of 60 to 75 percent strongly-zened, myrmekitic plagioclase (An₁₀₋₃₅), less than 10 percent microcline, 5 to 10 percent quartz, 5 to 10 percent hornblende, 1 to 5 percent biotite, and a total of less than 1 percent sphene, apatite, zircon, and magnetite.

The granodiorite appears to both intrude and grade into the granite. These two varieties of granitic rock are similar petrographically and mineralogically. Potassium-argon age determinations run by Geochron Laboratories, Inc. on biotite from the granite (AD-1) and granodiorite (AD-3) gave ages of $79.0(\pm 2.0)$ and $76.0(\pm 2.0)$ million years respectively (see discussion in Part II-Section A). These factors indicate that the two varieties probably are phases of the same intrusive, and thus are closely related genetically and were emplaced at about the same time.

The granitic body intrudes the Jurassic (?) metamorphic sequence, it intruded by the aplite-pegmatite, andesite, and rhyolite dikes, and is unconformably overlain by the Tertiary and Quaternary volcanic rocks. The stratigraphic relationships and isotopic age determinations indicate that the granitic body is of Cretaceous age.

Aplite-Pegmatite Dikes

Numerous aplite-pegmatite dikes, ranging from less than one inch to more than 20 feet in width, cut the granite. Most of these dikes are concentrated in a zone extending south along the western crest of the range and swinging southeast to the granite-metamorphic contact. There are several aplite-pegmatite "centers" within the zone; here the dikes are most abundant, commonly are larger than is the rule elsewhere, and have an irregular, criss-crossing pattern caused by the great variation in individual dips. As the dikes extend away from such "centers", they gradually pinch out, become less numerous, and assume the northwest trend and steep dip which is by far their most common attitude throughout the range.

Aplitic and pegmatitic material commonly occurs in the same dike, usually with sharp contacts. In most cases the aplite forms the borders and the pegmatite occurs as lenses, stringers, and continuous tayers in the centers. Some dikes change to quartz veins along their strike. The aplite-pegmatite dikes commonly are more resistant to weathering than the enclosing granite, and form bold, wall-like outcrops.

The aplite is white and sugary-textured. In thin section the aplite is allotriomorphic-granular, and consists of 30 to 40 percent quartz, 20 to 50 percent plagicalse (An_{5-20}), 20 to 50 percent microcline, 1 to 15 percent muscovice, and less than 1 percent biotite, epidote, chlorite, magnetite and rutile.

The pegmatite consists of coarse pink microcline and/or white albite containing cores of milky to gray quartz, and locally abundant coarse biotite flakes and some rutile, sphene, and allanite. Small amounts of zircon, cordierite, and epidote were noted in thin section.

The aplite-pegmatite dikes cut the granitic body and the metamorphic sequence, and in turn are cut by the andesite and rhyolite dikes. The field evidence suggests that these dikes were intruded as a late stage differentiated from the plastic portions of the granitic body. Potassium-argon age determinations (AD-2 and AD-6) run by Geochron Laboratories, Inc. on biotite from two atypical, biotite-rich pegmatitic dikes gave ages of $31.5(^{\dagger}2.0)$ and $66(^{\dagger}4)$ million years respectively. Recause the AD-2 biotite is highly altered to chlorite, the determination of 31.5 million years probably does not date the intrusion of the dike from which it was taken (see the more detailed discussion in Part II-Section A).

Andesite Dikes

Many andesite dikes intrude the granitic body, metamorphic rocks, and aplite-pegmatite dikes. Two andesite dikes cutting the volcanic rocks may also belong to this group. The dikes occur throughout the range but are much more abundant in the north half. These dikes are up to 50 feet wide; most trend roughly N. 50° W. in the north half of the range, and northeast in the south half, and have steep dips. Individual dikes commonly are straight, long, and relatively even in width. Some are more resistant to weathering than the enclosing rocks and form "walls".

Weathered material is blocky. Their dark green to black color makes them easy to trace in the field.

Dikes of this group range from diabase to diorite in composition, but mostly are hornblende andesites. All are quartz poor. Many dikes are porphyritic with phenocrysts of plagioclase and/or hornblende; others are aphanitic, and a few of the larger ones have perphyritic centers grading into aphanitic margins. The dioritic variety of this group is quite similar to the granodioritic variety of the rhyolite group, making it difficult to tell them apart in the field. The hornblende andesite contains 30 to 65 percent plagioclase (An₃₀₋₅₅), 15 to 60 percent hornblende, 2 to 5 percent magnetite, 0 to 5 percent biotite, 0 to 3 percent quartz, and less than 1 percent apatite. Propylitization is common in these rocks; the propylitic minerals include: chlorite, epidote, calcite, and quartz.

The andesite dikes — It the metamorphic — cks, granitic body, and aplite-pegmatite dikes. In most cases the andesite dikes are cut by the rhyolite, but the reverse relationship has been observed at several places. Faults that offset andesite dikes commonly are cut without offset by nearby rhyolite dikes. These relationships indicate that most of the andesite dikes are older than most of the rhyolite dikes, but that the intrusion of the rhyolite and andesite groups was at least partially overlapping in time. Undoubtedly some dikes assigned to this group in the field, actually belong in the rhyolite group discussed below.

Two diabase likes in the volcanic rocks and a diabase dike in the granitic body near its south end differ markedly from the dikes included with the andesite group. These diabase dikes are discussed in more detail under Quaternary-Tertiary volcanic rocks below, but were included with the andesite group on the geologic map.

Rhyolite Dikes

Light-colored rhyolite dikes occur throughout the range, and intrude the granitic body, metamorphic rocks, aplite-pegmatite dikes, and most of the andesite dikes. The rhyolite dikes are most common north of GZ Canyon in the north-central part of the range, south of the area of most abundant undesite dikes. These dikes are up to 50 feet wide; most trend roughly N. 50° W. in the north half of the range and northeast in the south half, and have steep dips. Although many of the rhyolite dikes are straight, long, and of even width like the andesite dikes, the younger rhyolite dikes most commonly are curved, short, and variable in width. These younger rhyolite dikes commonly crosscut without being offset, or are intruded along, faults that offset the older rhyolite dikes. Some rhyolite dikes form "walls," more commonly they do not, but they often do form the backbone of ridges. Weathered material is blocky.

The dikes of this group range from rhyolite to dacite in composition, and are porphyritic, phaneritic, and/or aphanitic. The three most common varieties are aphanitic rhyolite, quartz porphyry without feldspar phenocrysts, and porphyry with both quartz and feldspar phenocrysts. The dikes are white to buff, but commonly are stained brown and/or reddishbrown.

In this section the aphanitic rhyolite is allotriomorphic-granular with poikilitic and cuneiform intergrowths of quartz and K-feldspar; no other primary minerals were noted, but the feldspar commonly is almost completely argillized and sericitized. The porphyritic varieties of rhyolite contain up to 30 percent phenocrysts of quartz, sanidine, and/or albite in a microcrystalline groundmass of the same minerals plus 0-5 percent biotite; some sections show evidence of proplitization, argillization, sericitization, and/or pyritization.

No rhyolite dikes were noted in the volcanic rocks suggesting that the dikes are prevolcanic in age.

Intrusive Breccia

A breccia, consisting of inclusions of several rock types in a ground-mass of pink and white aplite and porphyritic rhyolite, is expected along the northeastern front of the range from Red Top Canyon to south of Breccia Canyon.

Most of the inclusions consist of the several varieties of andesite; granite fragments are rare. Most of the inclusions are assimilated to the extent that their original character is masked. The inclusions range from gravel-sized, sub-rounded pieces to masses which have dimensions of hundreds of feet. Commonly, the inclusions make up 20 to 50 percent of the rock, but they are absent over large areas.

The aplitic and porphyritic-rhyolite types of groundmass are gradational with each other, mineralogically and texturally. In thin section, the rhyolitic groundmass is porphyritic, with phenocrysts of albite and/or sanidine in a micro-crystalline groundmass of the same minerals and biotite. The aplite is composed of approximately equal amounts of quartz, K-feldspar, and albite. Variations in composition probably are due in part to the assimilation of other rock types. At the north end of the exposure, part of the groundmass is a medium-grained granitic rock composed of pink K-feldspar, quartz, and lesser white plagioclase feldspar. Locally, masses of coarse pink feldspar, with cores of gray quartz, occur in the granitic variety of the groundmass.

The intrusive breccia cuts the granite. The aplitic groundmass of the intrusive breccia extends outward from the main mass in the form of dikes which cut andesite dikes and granite. Where the andesite dikes extend into the intrusive breccia body they are broken and enclosed by the aplitic groundmass, and become increasingly difficult to trace as they extend further into the body. In contrast, the rhyolite dikes grade into the groundmass of the intrusive breccia body, the groundmass and dikes being quite similar both megascopically and microscopically, giving the impression that the dikes were feeders for the intrusive breccia body or were fed by it. Thus the intrusive bre cia is younger than at least some of the andesite dikes, and appears to be closely related to the rhyolite dikes, loth in time and genesis. Some of the aplite-pegmatite dikes elsewhere in the range also may be related in time and genesis to the intrusive breccia (see discussion under Aplite-Pegmatite Dikes above.).

Quaternary-Terriary Volcanic Rocks

Quaternary-Tertiary volcanic rocks unconformably overlie the metamorphic rocks at both ends of the range and lie directly on the granite in several hills on Fourmile Flat to the west. An upper, Quaternary(?) unit of basalt flows rests with varied degrees of angular unconformity upon a Tertiary(?) unit consisting of an upper member of light-colored rhyolitic pyroclastics and flows and a lower member of dark-colored andesite flows.

North of U. S. 50 on the cast slope of the range several small erosional remnants of rhyolite vitrophyre are present near the top of the rhyolitic sequence. Probably all of these are at the same stratigraphic position and represent one large tabular, horizontal, shallow, glassy intrusive body or possibly an extrusive dome. The base and top of the vitrophyre are not present in any one exposure, but the body is probably less than 100 feet thick.

The andesitic lower sequence rests with pronounced unconformity on the Mesozoic(?) metamorphic rocks in the northern end of the range. Locally the rhyolitic sequence rests directly upon the metamorphics. In the southern-most part of the map area both the Quaternary(?) basalt and upper Tertiary(?) rhyolitic sequence are present, but the andesitic sequence is missing.

The Quaternary(?) basalts rest with discordances of up to 30° upon the Tertiary rhyolite and form horizontal to gently westerly-dipping "mesas" in contrast to the "badlands" topography developed in the rhyolites. A "baked" and highly oxidized reddish-orange zone 20-25 feet thick is commonly present at the upper contact of the rhyolitic sequence. The lowermost five feet or so of basalt is commonly an "erosional breccia". It consists of boulders up to 18 inches in diameter, which probably existed on an old erosion surface and have been incorporated into the base of the flow. The basalt is generally vesicular, rarely amygdaloidal, and is locally extremely scoriaceous. North of U. S. 50 the basalt sequence generally dips 15°-20° northwesterly to westerly.

Although the rhyolites at the north and south ends of the range are undoubtedly stratigraphic equivalents, there are some noticeable differences in lithology. Felsite flows predominate more in the southern exposures than in the northern ones; the latter have considerable amounts of tuffaceous material. The glassy vitrophyre prominent north of U. S. 50, has not been noted in the souther exposures.

The volcanic rocks of the Sand Springs Range are dated as Quaternary(?) and Tertiary(?) on the basis of their relationship to other rocks in the area and their similarity to the Quaternary and Tertiary volcanic rocks in other nearby areas.

Quaternary-Tertiary Sedimentary Deposits

Quaternary and Tertiary alluvial and eolian deposits occupy the valleys east and west of the range. Fairview Valley east of the range is

characterized by bolson deposits. On the basis of geophysical stuffes (see separate chapters of Part I), this unconsolidated material is estimated to be as thick as 5,800 feet near the west margin of the valley a few miles south of U. S. Highway 50. In the same general area, at hydrological test hole H-4, the alluvium is known to be over 980 feet thick. (See Figure 10.)

Fourmile Flat west of the range is covered by alluvial fans, pediment sands and gravels, and sand dunes, playa lake deposits, and Lake Lahontan beach deposits and tufe. Thick alluvial fans occur along the west front of the Sand Springs Range and along the northeast front of the Cocoon Mountains, sloping west and northeast to the playa lake of Fourmile Flat. Sand dunes are common around the edges of the playa, and wind-blown sand mantles large areas of the alluvial fans and granite pediment. Unusually large dunes, over 400 feet high, are present north of U. S. Highway 50 at the northeastern edge of the flat; sands are deposited here as the prevailing northeast winds lose velocity and carrying power at ground level in rising to pass over the range. A "tail" of sand extends nort heastward across this low point in the range. The slopes of both the alluvial fans and the volcanic rocks at the north end of the range are conspicuously cut by Lake Lahontan terraces and covered by beach pebbles and tufa to an elevation of about 4,380 feet. The thickness of the alluvial fill in Fourmile Flat is much less than that in Fairview Valley. In hole H-3 bedrock is believed to have been encountered at 310 feet; however, a refraction profile centered at the well gives a depth of 196 feet to a high velocity layer which was tentatively identified as being composed of metamorphic rocks. About one and one-half miles down the alluvial slope (northwesterly), at hole H-2, bedrock was not encountered at 780 feet, the total depth of the well. Gravity measurements reported in the subsequent geophysical section suggest depths of less than 1,300 feet to bedrock immediately south of the salt flat. (For a more detailed description of the Quaternary-Tertiary sediments, see Hydrogeology and Hydrology section of Part I and Part II-Section B.) Windblown silty material mantles several of the major depressions in the crest of the Sand Springs Range. The extent of the silt is not indicated on Plate 4, but it is the major cover in the Ground-Zero area, averaging less than 10 feet.

STRUCTURES

Folding

Folding is not a prominent feature in the Sand Springs Range. The metamorphic sequence at the south end of the range apparently forms the western limb of a south-plunging anticline, the eastern limb being in Slate Mountain. Smaller scale folding in uncommon in the Sand Springs Range except along the southern granitic-metamorphic-rock contact where some drag folding of the metamorphics was noted.

Faults

The Sand Springs Range is a north-trending fault-block that has been subjected to intermittent tectonic activity. The range has been uplifted

along a series of high-angle, northeast- and northwest-trending faults. These faults have a remarkably consistent pattern through the range. The fault-block making up the range appears to be tilted, with the western side remaining higher. The recurring faulting and accompanying joints and cleavage provided the majority of avenues and sites for the intrusion of the aplite-pegmatite, rhyolite, and andesite dikes.

Northwest-Trending Faults: These faults, trending more or less N. 500 W., are accompanied by parallel joints. Most of the aplite-pegmatite, andesite, and rhyolite dikes are intruded along these faults and joints. Several wide northwest-trending zones of alteration are associated with the faults. Because the dikes commonly follow rather than cross-cut these faults, the faults are difficult to detect; however, they probably are as common as the northeast-trending faults.

Although most of the faults are narrow, a few are wide, and some are grouped together to form fault zones. Many contain gouge and brecciated wallrock. Both the wider individual faults and the fault zones contain numerous irregular slips. Wallrock fragments in the faults, and the adjacent wallrock, commonly are iron-stained, bleached, propylitized, and brecciated.

These faults show both horizontal and vertical movement. Topographic expression, slickensides, and offsetting of the volcanic rocks and thrust fault suggest that the predominate movement along some of these faults was vertical, in many cases being hundreds and even thousands of feet. However, the offsetting of vertical dikes and the northeast-trending faults, and the direction of slickensides, indicate that horizontal movement is late and most commonly is small, being measurable in tens and rarely in hundreds of feet.

Faults of this group offset the metamorphic rocks, granite, and volcanic rocks, and in a few cases the Quaternary alluvium and various types of dikes. The thrust fault also is offset, while the northeast-trending faults both cut and are cut by the northwest-trending ones. Some of all three types of dikes, except the younger, curved rhyolites, are intruded along these faults, but show no evidence of post-dike movement. None of these faults were found to be cut by granite. The evidence thus indicates that they have been active intermittently from shortly after the intrusion of the granitic body until recent times, with the periods of greatest activity before injection of the dikes and after extrusion of the Quaternary volcanics.

Northeast-Trending Faults: The faults which trend more or less N. 30° E. are accompanied by closely spaced parallel fracture cleavage. Although many of these faults are narrow, some are wide, and others are grouped together to form fault zones. Most contain gouge and brecciated wallrock, and the wider individual faults and the fault zones contain numerous irregular slips. The breciated wallrock fragments in the faults, and the adjacent wallrock commonly are iron-stained, bleached, and propylitized.

Topographic expression, slickensides, and offsetting of the thrust fault indicate that in some cases the predominate movement along these

faults was vertical. However, offsetting of the dikes and northwest-trending faults, and directions of slickensides, indicate that horizontal movement has been common along most of these faults, with total obvious displacement seldom being more than a few tens of feet. So many faults have this northeast orientation that only those with the most persistence and largest displacements could be mapped without obscuring other geologic features. As the amount of movement becomes smaller, the faults are lost in fracture cleavage.

Faults of this group offset the metamorphic rocks, granite, dikes, volcanic rocks, and in a few cases Quaternary alluvium. The thrust fault is offset by faults of this group, while the northwest-trending faults both offset and are offset by these faults. Most of the faults offset all the dikes except the younger, curved rhyolites, but are not cut by the granite. The evidence thus indicates that movement occurred intermittently from shortly after the intrusion of the granite until recent times, with the periods of greatest activity before the intrusion of the younger, curved rhyolite dikes and after the extrusion of the Quaternary volcanic rocks.

Thrust Fault: A thrust fault cuts the metamorphic rocks at the north end of the range. It has a gently-north-dipping undulating surface. The upper plate is garnetiferous, recrystallized limestone. The lower plate is metamorphic rocks, except in two small areas where small offshoots of the granitic body are exposed in contact with the thrust. Along the sole of the thrust the rock is bleached and stained. The direction of movement is not known. The reconnaissance mapping suggested no thrust faulting elsewhere in the range.

Joints

A well-developed system of joints parallels the northwest-trending faults. The joints can be recognized in the bold outcrops in the southeast corner of Plate 1. All the dikes except the younger, curved rhyolite ones are intruded along these joints. Apparently most of the joints had already been filled by the time the curved rhyolite dikes were intruded, and these dikes were forced in part to follow less regular fractures. However, numerous northwest-trending joints are present which do not contain dikes, suggesting that a second, post-dike period of joint-formation occurred or that the dike magma was insufficient to fill all joints. It is likely that the joints and the northwest-trending faults were formed simultaneously and by the same forces.

Fracture Cleavage

The well-developed fracture cleavage present throughout much of the granitic body commonly parallels the northeast-trending faults. Tocally the fracture cleavage has other orientations. Individual surfaces are irregular but roughly parallel to one another. In most cases, the fracture cleavage consists of sub-parallel planes 1/10 to 1/5 of an inch apart. Intersection of fracture cleavage and joint surfaces locally causes partially decomposed grante to break into spindle shapes.

Movements of less than an inch have taken place along many of the surfaces, and minor amounts of gouge are present on some surfaces. The darision between faulting and fracture cleavage is arbitrary, and many of the more through-going surfaces could be considered as joints.

Well-developed fracture cleavage cuts the aplite-pegmatite dikes; fracture cleavage cuts the other dike types but is less well-developed. The fracture cleavage probably was formed at the same time as, and by the same forces that caused, the northeast faulting, with most of the fracture cleavage apparently formed during the post-granite, pre-andesite-dike period of the northeast-faulting. During the post-Quaternary volcanic period of faulting, pressures probably were relieved along pre-existing faults and fracture cleavage surfaces, and relatively little additional fracture cleavage developed at this late stage of faulting.

Other Faults, Fracture Cleavage, and Joints

Other directions of faulting, fracture cleavage, and jointing have been recognized but do not compare in prominence or consistency with those just described. Such fracture cleavage and jointing commonly parallels and are associated with faults having unusual orientations.

ALTERATION

Little wall rock alteration occurs along the aplite-pegmatite and andesite dikes. In contrast, many of the rhyolite dikes and the granite which they intrude contain disseminated pyrite, and are bleached, argillized, and iron-stained. Propylitization, bleaching, argillization, and iron-staining also are common along many of the faults and some of the joints in the granitic body and volcanic rocks, and to a lesser extent in the metamorphic rocks. Except for a belt trending northwest across the range at Breccia Canyon north of GZ Canyon and an area at the head of Lucky Boy Canyon, the alteration affects only a very small fraction of the total rock. At Breccia Canyon the fluids causing the alteration, as well as a swarm of rhyolite dikes, took advantage of the openings provided by a belt of northwest-trending faults.

ORE DEPOSITS

Tungsten Contact-Metasomatic Deposits

Contact metasomatic tungsten deposits occur in the metamorphic sequence at the north and south ends of the range along the contact with the granitic body, in most cases in limestone. Scheelite and minor powellite occur with garnet, calcite, quartz, cordierite, diopside, and other skarn minerals forming small, irregular replacement bodies. Small, irregular quartz veins containing scheelite cut the replacement bodies and surrounding rocks.

In recent years, extensive prospecting has been done in these deposits but with unfavorable results. Although a small amount of tungsten ore has been mined, the deposits are too small, irregular, and low-grade to be worked profitably. Although some assessmer, work has been done, none of the mines were active in 1962.

Silver-Gold Veins

A system of east-west veins dipping steeply south, occur in a sheer zone crossing the range just south of U. S. Highway 50. The veins cut metamorphic rocks, Tertiary volcanic rocks, and andesite and rhyolite dikes that occupy many of the individual fault strands. The veins are offset short distances by cross-faults. At the surface the veins have a braided pattern. The main southernmost vein dips 70° to 80° south; the subsidiary veins to the north dip 50° to 70° south and intersect the main vein at shallow depths.

The veins are 2 to 10 feet thick, contain fine-grained to vuggy quartz, angular fault breccia, and locally abundant calcite and pyrite. Values reportedly occur in free gold, cerargyrite, and argentite. The ratio of gold to silver is 1:40 in the upper level but increases to 1:80 in the deeper workings. At the surface and in the upper level the vein is highly oxidized, and the quartz crumbles readily.

Extensive underground workings reach depths in excess of 450 feet. The principal workings are known as the Summit King (Dan Tucker) mine. The deposit reportedly was discovered in 1905 but was not explored until 1912 when a 130-foot shaft was sunk on the main vein. In 1919 several additional shafts were sunk and 150 tons of ore running \$125 to \$300 per ton was shipped. From 1937 through 1941 and from 1948 through 1951, a total of 1,262,655 cunces of silver and 20,895 ounces of gold were recovered by a cyanide mill on the property.

Quartz Veins

A north-south, gently-west-dipping quartz vein over 15 feet thick, crops out in a hill along the east front of the range south of Lucky Boy Canyon. The vein is exposed on a dip slope, thus has an extensive outcrop. It is a portion of an aplite-pegmatite dike in which quartz is the only mineral. The deposit has been prospected as a source of high-purity silica. A number of other narrow, gently-dipping, vuggy, white quartz veins occur in the range. Desultory prospecting suggests they are not worthy of exploitation.

Sodium Chloride Deposit

Salt is harvested annually from the playa on Fourmile Flat. Winter snows and rains result in a portion of the playa being filled with salt-laden water. A crust of salt cubes up to an inch across remains after the water evaporates during the hot summer weather. This crust is scraped up and sold, mainly for ice-removal on city streets and highways, and as stock-salt.

Geology of Area B, Including Trenched Area by Laurence H. Beal, S. E. Jerome, and John H. Schilling

The lithologic and structural elements in the immediate Ground-Zero area have been disclosed by 1:6,000 scale mapping of Area B, by 1:2,400 scale mapping of bulldozer trenches, traverses on which mapping was done on 1:2,400 scale, and by an inclined drill hole (ECH-A, N. 60° W., -45°, bottomed at 1,898 feet) and a vertical drill hole (ECH-D, bottomed at 2,017 feet). Results of this work are presented on Plates 4 and 5. Geological information resulting from underground openings, trenches, and drill holes completed during the operational stage of Shoal also has been added to Plates 4 and 5.

SURFACE GEOLOGY

The structural and lithologic elements are quite simple within 2,000 feet of tentative Ground-Zero, near the collar of ECH-D, and are relatively simple throughout Area B. The principal country rock is Ground-Zero ty e granite whose petrographic characteristics have been detailed above.

Although the granite has a variety of joints with both steep and gentle dips, the most prominent and consistent joint set strikes N. 50°-60° W., and dips vertically to steeply NE or SW. This set is recognized throughout the Range. Some adjustment has taken place on a few of these joints in the Ground-Zero area (see Plate 5) east of the intersection of trenches 3N and 1W, north of the east end of 1S, at 3N-6W, and from 5S-2W and 5S-4W northwestward. These adjustments normally are expressed by thin seams of gouge less than an inch in width. Discontinuous siliceous breccia up to 4 in. wide is occasionally present. The planes of breaking and adjacent granite walls often show some propylitization and bleaching in bands that rarely exceed 10 feet in width. These planes have had recurrent movement and probably are related to the major northwest-trending zones several miles north of Ground-Zero, many of which show strong sericitization over substantial widths and are locally occupied by rhyolite and andesite dikes. fault, discovered during shaft sinking, is a major representative of the northwest joint set along which faulting has taken place.

Along the west side of the bulldozer trench grid, aplite-pegmatite dikes, remarkable for their consistency in strike and dip, have invaded the northwest joint set. This zone of abundant dikes extends north and south beyond the limits of Area B. Where exposed in the grid they vary from a few inches in width up to a maximum of about 6 feet. As these dikes are traced southeastward, they diminish in number and become narrower in width; most die out within a thousand feet of the road along the west side of the grid. In the east half of the grid all visible dikes were mapped, regardless of width, to disclose the structural pattern. Very few dies were found within 1,000 feet of tentative Ground-Zero, and all but one or two are less than a foot wide. It will be evident from examination of Plate 4 that west of the grid the northwest-trending dike pattern while still predominant, is complicated by a greater number of wider dikes showing more variable strikes and dips. Walls of the dikes usually are frozen to fresh granite but they occasionally show slippage, and the granite may be bleached for a few feet

from the walls. The two hills along the range front west of the trenched area are held up by abundant erosion-resistant aplite-pegmatite dikes.

In addition to the aplite-pegmatite dikes, a single mass of porphyritic granodiorite, 50 feet wide by 100 feet long, was mapped west of 5W on 5S. Two narrow andesite dikes, also in this joint set were recorded on 8S. Two short andesite dikes were mapped about 1,600 feet east of drill hole ECH-D. Numerous rhyolite dikes and several andesite dikes occur in Area B northeast of the trenched area; only a few rhyolite and andesite dikes crop out in Area B south of the trenched area. These dikes show the same features and relationships as elsewhere in the Range.

Throughout the trench grid the granite mass and the aplite-pegmatite dikes are cut by fracture cleavage that varies in intensity from about 6 to 20 megascopic planes to the inch; an average for the grid exposures is about 10 to the inch. The strike of the cleavage averages about N. 30° E. and is impressive for its consistency; its dip is vertical to steep NW or SE. Elsewhere in Area B the cleavage commonly has the same strike and dip, but other orientations are prominent locally. This phenomenon, spectacularly exposed in the ripped trenches probably is the consequence of horizontal compression and must be intimately related to the faults which angle northeasterly across the Range. In many cases slippage along cleavage planes offsets aplite-pegmatite dikes for short distances; however, no consistent pattern of offset is evident. These slip planes usually lack gouge or alteration and are not detectable except where they offset segments of the dikes.

The principal northeast-trending fault zones are designated on Plate 5, proceeding from east to west, as "A", "B", "C", and "D"; a fifth zone, "E" is unique in that it strikes about east-west.

"A" is a major zone which, with nearby elements, is one of the most prominent features of the Range. In the Ground-Zero area it is several hundred feet wide and is expressed at surface by a rib of silicified breccia up to a foot wide, dipping 55° to 80° NW. Granite adjacent to the rib is bleached, propylitized, and cut by numerous fracture planes.

"B" fault zone, about 50 feet wide, is marked at surface in a fashion similar to "A" except that it dips 75° SE. Thin gouge elements in the zone vary in their strike and in their degree of southeasterly dip. The "B" zone apparently is a hanging wall split of "A" zone.

"C" fault is identified at several places in the southern part of the grid by bands of bleached granite 20 to 30 feet wide, that are cut by multiple gouge seams. Reliable dips were not obtained there. On 1W between 3N and 4N, "C" zone includes 1 and 1/2 inches of gouge and breccia and several half-inch wide sympathetic gouge planes in a 40-foot band of somewhat bleached and propylitized granite. The only reliable dip obtained there was vertical. Another plane 30 feet to the west dips 85° SE. Three unnamed faults parallel to "C" were recognized between 3S and 8S, but evidence is lacking for carrying them through the northern part of the grid. Two of these, Fault Zones #1 and #2 (Plate 5), were shown by underground

work to extend northeastward from where they were mapped on surface in the south grid. In conjunction with "F" fault they made bad ground near the bottom of the shaft and on the level.

"D" fault zone includes several elements identified by offsets on aplite-pegmatite dikes; otherwise it is poorly exposed. What appear to be splits from the zone are exposed as thin gouge seams in somewhat bleached granite in the diagonal bulldozer trench between 3N-6W and 2N-7W.

Supplementary bulldozer trenching in August 1962 disclosed between 3N and 4N a 30-foot-wide zone, striking east-west, of strong bleaching and abundant gouge seams showing diverse strikes and dips. This is designated "E" fault zone. It is not known if it persists beyond "B" and "C" zones. Study of its elements, especially in the trench on the south side of the ridge, indicates the dips vary between vertical and 53° south. In the hanging wall of "E" are two 3- to 5-foot zones of slippage and bleaching which dip vertically to steeply north. These are sub-parallel to the northwest joint set.

The same northeast-trending pattern of faulting that is present in the grid is prominent throughout Area B except in the southeast corner of the area where a more random pattern is evident.

The details of the geological structure discussed above were, prior to trenching, obscured by fine silt commonly less than 10 feet thick, which is believed to have been blown in from Fourmile Flat to the west. The granite apparently was altered only by shallow physical weathering before the rock was inundated by silt, because the granite ripped in the trenches, while commonly limonite-stained, shows little decomposition of its feldspars or ferromagnesian minerals. A narrow band of caliche and bleached granite often occurs between fresh granite and the silt cover. Caliche also occurs along some of the fault zones.

SUBSURFACE GEOLOGY

In order to test ground conditions in depth, holes ECH-A and -D were diamond drilled. (See Plates 4, 5 and 8 and Appendices A and B.)

Exploration core hole ECH-A (N. 60° W., -45°) was completed at a drill hole depth of 1,898 feet. The hole steepened to about 49° at its bottom, approximately 1,500 feet lower in elevation than the collar of ECH-D and approximately 150 feet S. 60° E. of the downward projection of ECH-D. The following was encountered (See Appendix A for more details.):

- 0- 55 ft.-soil and decomposed granite.
- 55- 120 ft.-weathered granite.
- 120- 450 ft.-FAULT ZONE: gouge and brecciated, bleached, and propylitized granite. The core is soft and crumbly.
- 450- 600 ft.-fresh granite; hard, relatively solid and unaltered.
- 600- 890 ft.-FAULT ZONE: (same as 120-450 ft.).
- 890-1898 ft.-fresh granite; (same as 450-600 ft.); some, less than 1-inch gouge (fault) seams.

Exploration core hole ECH-D (vertical) was completed at a drill hole depth of 2,017 feet. The following was encountered (see Appendix B for more details):

0- 307 ft.-no core. Cuttings indicate granite is fresh.
307-1440 ft.-fresh granite; (same as fresh granite in hole ECH-A)
1440-1675 ft.-FAULT ZONE: alternating breccia and gouge, and bleached,
propylitized, and fresh granite.
1675-2017 ft.-fresh granite; some narrow gouge (fault) seams:
bleaching along fractures and faults.

The fault zones in the upper part of ECH-A correlate with the north-east-trending high-angle faults (Zones A and B) observed southeast of the proposed Ground-Zero point during surface mapping. No significant high-angle faulting is present in the lower part of ECH-A; however, a number of gouge (fault) seams less than 1 inch in thickness were encountered. The fault zone in ECH-D probably is the downward extension of the "E" fault zone. Because of the uncertain nature of its dip at the surface, "C" fault also may intersect ECH-D in the same interval. (Underground work proved this to be so.) Many ribs of relatively solid granite occur in the fault zone; and an unusually large amount of core fell out of the core barrel while being pulled, then was reground during firther drilling, producing material that makes the interval appear to be more broken than it is. No evidence of thrust faulting has been noted in either hole.

The northeast-trending fracture cleavage and northwest-trending joints observed on the surface are present throughout the entire lengths of both holes but are increasingly "tight" with increasing depth. In the last 750 feet of ECH-A the core commonly breaks at 90° to the core axis rather than along joints or cleavage; in this interval exceptionally long pieces of core were recovered and many intervals of the granite approached "tombstone" quality. Except for the fault zone, the core from ECH-D compares favorably with the last 750 feet of core from ECH-A.

Only two narrow aplite-pegmatite dikes have been encountered in ECH-D and none in ECH-A. This almost complete absence of dikes in the two holes and at the surface in the vicinity of proposed Ground-Zero makes it unlikely that a swarm of dikes might be present within several hundred feet of ECH-D.

Although alteration (propylitization, bleaching, and iron-staining) is common along joints, fracture cleavage, and faults, relatively little rock has been affected, and the rock a few inches from the structure usually is fresh, solid, and dense. However, the rock in the major fault zones commonly is highly altered.

In Part II - Section A an analysis is made of geophysical logs of ECH-D completed by Schlumberger Well-Surveying Corp.

GEOPHYSICS

Gravity Survey by James I. Gimlett

INTRODUCTION

The gravity survey was designed to investigate the flanks of the Sand Springs Range and the neighboring valleys. It was expected that it would be possible to determine the Basin-Range fault pattern and arrive at reasonable estimates of the displacements involved. The efficacy of the gravimetric method for solving this type problem is due to the large density contrast between the dense metamorphic and granitic rocks comprising the Range and the less dense sedimentary (and possibly volcanic) deposits of the valleys.

It is obvious that the expected gravity pattern should correspond clc ly to the topography--a gravity high over the Range and gravity lows over the valleys. That this is so can be seen with a glance at Plate 6, which is the complete Bouguer anomaly map of the area.

A gravity profile along U. S. Highway 50 across this area was run by Thompson (1959). His paper should be referred to for the regional picture.

FIELD MEASUREMENTS

The location of all gravity profiles and the six isolated gravity stations are shown on Plate 6. All profiles are east-west, i.e., roughly perpendicular to the trend of the Range, except those along U. S. Highway 50. It is believed that increasing the number of profiles would not materially improve the gravity pattern obtained. A 500-foot station spacing was used on all the profiles. This spacing is probably too tight in many cases, especially those with steep gravity gradients and those out in the valleys, and thus serves only as a redundancy check of data accuracy. For low-gradient areas near the kange, such a spacing is useful. Also, since most field time for the control surveying and for read the meter is spent in finding and getting to the stations, rather than at a station, a 500-foot spacing does not take appreciably longer than, say a 1,000-foot spacing.

The photogrammetric and gravity control were planned together as a unit. The stations on the east and west control traverses, which parallel the Range, also were utilized as gravity observation points. As these stations were, for the most part, less than 900 feet apart, these fifteen-mile-long gravity traverses provided detailed information on cross-trending (east-west) features.

The stations on all profiles and the two traverses were located using transit (or theocolite) and chain. All elevations were obtained by differential leveling. Six map-identifiable points were used as gravity stations in the Ground-Zero area. The elevations and locations of these

points were taken directly from the topographic map of Area B. In all, 737 stations were occupied during the course of this survey.

Gravity measurements were made with two Worden gravity meters. Most readings were taken with a "Master" gravity meter, which had a sensitivity of 0.1064 mgal/division. The remaining stations were occupied with an "Educator" meter with a sensitivity of 0.4657 mgal/division.

U. S. Coast & Geodetic Survey B.M.X-40, at the intersection of U. S. "ighway 50 and the road to the Nevada Scheelite mine, was selected as the primary gravity base station for this survey. Secondary base stations were established along both traverses by the method of loops. Normal Field procedure involved reading the gravity meter at either the primary base or one of the secondary bases every two hours.

DATA REDUCTION

All field measurements were reduced to the B.M.X-46 base. Returning to the previously established base stations every two hours made it possible to simultaneously correct for both the tidal variation and the instrument drift. As a check, the tidal variations were computed for ten of the survey days. The "Master" gravity meter was found to drift as much as 0.5 mgal in 6 hours, often nonlinearly. In fact, the "Master" meter drift in mgal was about equivalent to the "Fducator" drift. In view of the large anomalies encountered, the "Master' meter's drift was not excessive. However, it did negate, in part, the increased sensitivity advantage of the "Master" over the "Educator."

The complete Bouguer anomaly as used in this paper is defined (in mgal) as: 979,676.12+ g_m +0.05998h- g_0 + g_t It should be noted here that the word "complete" means that terrain corrections (g_t) were computed; if they had not been, the word "simple" would have been used.

The first term in the expression, 979,676.12, is the measured gravity at B.M.X-46, as determined by Thompson (1959). According to D. Mabey of the U. S. Geological Survey (oral communication), Thompson's value may be in error as much as 1 mgal. This is not surprising as his survey was tied to the old U.S.C. & G.S. pendulum station at Mystic, California. This did not affect the survey of this report, which deals with the local, rather than the regional picture.

The second term of the equation, g_m , is the measured difference with respect to the B.M.X-46 base. Errors in reading and in the drift removal process are probably less than 0.1 mgal for the "Master" and less than 0.2 mgal for the 'Educator" gravity meter. Another possible source of error is in the alibration constants of the two instruments. They were not checked, but it might be noted that the two meters were in agreement to within 0.1 percent.

The term 0.05998h is the combined free-air--Bouguer correction; h is the elevation in feet-above sea level. The crefficient corresponds to an assumed density of 2.67g/cc for the underlying rock. This value

is in accord with the standard practice of the U.S.C. & G.S., and was also used by Thompson. This figure is very close to the average density of the granitic rocks in the Sand Springs Range. For the small range of elevation encountered in this survey, errors in the assumed Bouguer density did not greatly affect the local anomalies. Since the elevations of all but six of the stations were obtained by double rodding or by traversing between bench marks, they should be accurate to less than a foot. Hence, errors in elevation should be a negligible source of error in the complete Bouguer anomaly.

The theoretical gravity at sea level, go, was determined by using the International Gravity Formula of 1930. Nevada Transverse Mercator coordinates were available for all gravity stations. Thus, it was a relatively simple matter to obtain the latitudes of all stations. In actual practice, a latitude correction was applied rather than calculating the latitudes and inserting them into the international formula. Inasmuch as the locations of all stations are known to within 50 feet and the latitude correction amounts to about 0.24 mgal/kft, the theoretical gravity term should introduce negligible error into the complete anomaly.

Terrain corrections, g_t , were computed for 52 stations using the Hammer method out through zone M (71,996 ft.). The terrain corrections for all other stations were then found using a graphical interpolation procedure much like that presented by Winkler (1962). The accuracy of the interpolation is greatly enhanced by the essentially two-dimensional nature of the topography. In addition, the smoothness of the simple Bouguer anomaly curves lends confidence to the graphical approach.

A density of 2.67 g/cc was used in determining the terrain corrections. This is the same as the Bouguer density, thus taking care of the "holes" in the Bouguer plate, and is close to the average density of the mountains above all the gravity stations. The largest terrain correction encountered was 7.59 mgal at the radio relay tower, the smallest 0.36 mgal near Frenchman Station. The average of all 52 stations is 1.54 mgal.

The uncertainty in the terrain correction is estimated to be on the order of 0.2 mgal. Thus it is the least accurate term in the formula for the complete Bouguer anomaly, at least insofar as the local (or relative) anomaly is concerned. As a result, the overall probable error of the local anomaly is estimated to be somewhat less than 0.3 mgal.

GRAVITY MAP AND PROFILES

The gravity data were plotted and contoured on a 1.0 mgal interval as shown on Plate 6. Over the top of the Range the contouring is conceptual rather than actual; there the contours are dashed. Where the gravity control is adequate the contours are shown as solid lines. Inasmuch as all gravity profiles and stations are shown on the map, the validity of the contouring in any area should be obvious.

The profiles are self explanatory. Omitting the westernmost 8.000 feet, the gravity data and geologic profile A"A" (except for the fault shown out from the Sand Springs Range) is taken from Thompson (1959).

QUALITATIVE INTERPRETATION

As was expected, there is a one-to-one correspondence between the gravity pattern and the topography. The steep gravity gradient along the eastern side of the Range would seem to indicate normal faulting with large displacements. Since the gravity contours closely parallel the front of the Range (notice partic larly the -175 contour) it is evident that the present topography is largely controlled by this faulting. From surface evidence it is apparent that the Range is bounded on the east side by a series of northwest- and northeast-trending faults instead of by one north-south fault. These faults have similar vertical displacements and are perhaps contemporaneous.

The rather flat gravity gradient along the northwest flank of the Range would seem to indicate a rather featureless bedrock surface dipping basinward at a low angle beneath Fourmile Flat. No faulting with large displacements is noted here. If such faulting does exist, it does not bring rocks of markedly different densities into juxtaposition. The gravity picture here is somewhat obscured by a gravity high centered some one-half mile north of U. S. Highway 50. This feature is discussed later in this section.

There is a topographic and gravity high between the Sand Springs Range and the Cocoon Mountains south of Fourmile Flat. In view of the exposures of granitic and metamorphic rocks seen there, this saddle is more closely akin geologically to the Sand Springs Range than to the basalt-capped Cocoons. These relatively dense granitic and metamorphic rocks are responsible for the gravity high.

South of the saddle, along the southwest flam! of the Range, steep gravity gradients again prevail. This would indicate normal faulting. As this area is some distance away from Ground-Zero, it will not be discussed further in this report.

Although the Range is marked by a gravity high, the crest of the high is displaced to the west. In the vicinity of Fourmile Flat the gravity high is located up to 3,500 feet west of the edge of the Range. The anomaly here is about 10 mgal higher than it is over the granites. The obvious conclusion is that this difference is caused by rocks heavier than the granites. In view of a similar high (with respect to the granites) both over the metamorphics in the southern half of the Range, and in the small "window" of metamorphics present at about the center of the northern high, it is likely that this feature is caused by a relatively thick metamorphic rock section along the west margin of the Range. The lack of large anomalies on the aeromagnetic profiles would seem to deny the presence of ultrabasics in this region.

The gravity nose extending out into Fairview Valley south of Lucky Boy Canyon is also marked by a small aeromagnetic high (Plate 7). This feature is interpreted as being the result of a shallow, buried horst, capped with metamorphics.

As to be expected over a high continental area, the Bouguer anomaly is strongly negative. Thompson's (1959) paper discussed the regional picture. He stated that the isostatic compensation in this area is regional, i.e., each range is not locally compensated, and that, if anything, this region may be slightly overcompensated.

QUANTITATIVE INTERPRETATION

The most important factor in interpreting gravity surveys is rock density. For the purposes of this survey all rocks were grouped into three density categories: (1) the intrusive rocks of the Sand Springs Range and all Quaternary and Tertiary volcanic rocks in the Sand Springs and neighboring Ranges, (2) the metamorphic rocks, and (3) the valley-fill deposits.

The rocks of group 1 are assumed to have a density of 2.67 g/cc. This figure is within 0.05 g/cc of the average of S.S.D. measurements made by the interpreter on specimens from this and similar intrusives. The volcanic rocks are unimportant for this survey except for those exposed in Fairview Peak. In the Sand Springs Range they provide only a thin cover in the areas of interest. The average density of these rocks depends greatly on the amount of pyroclastics and tuffaceous sediments in the volcanic section. 2.67 g/cc is probably a good estimate.

The metamorphic section includes rocks with measured densities ranging from 2.8 to 3.1 g/cc. Recrystallized limestone and phyllite-hornfels, the two most common metamorphic rock types, have densities at the low and high ends of the range, respectively. Assuming the metamorphic section to be composed of equal amounts of recrystallized limestone and phyllite-hornfels, the density of the group 2 rocks was somewhat arbitrarily taken as 2.97 g/cc, giving a contrast of 0.30 g/cc for use in constructing the geologic profiles of Plate 6.

The density of the valley-fill deposits is even more imperfectly known. By their very nature the valley-fill sediments do not outcrop in the Range. No wells are known to penetrate to "bedrock" in the thicker areas, hence, not even the lithology, much less the density, of this light material is known. Lacustrine and subaerial sediments of varying degrees of compaction probably predominate in the section. There also may be a sizeable thickness of volcanic, both pyroclastic and flow, rocks in the valley.

Following Thompson and other workers in the Great Basin, a density contrast of 0.50 g/cc was used to determine the depth to "bedrock" in the two geologic profiles. The valley-fill is thus assumed to have a density of 2.17 g/cc. The 0.50 figure has the one virtue of giving reasonable depth estimates in most areas. For this area the computed 5,800 foot depth in Fairview Valley is in good agreement with the depth obtained from the aeromagnetic data. In many valleys it may be that the most valid density contrast can only be determined gravimetrically using depths determined by drilling or from seismic surveys.

In most gravity surveys in the Basin-Range province, the "bedrock" surface beneath the valleys is a mathematical rather than a geologic surface, referring to the lower bounding surface of a volume of rocks, which, if the

rocks have the assumed density contrast, would produce the observed gravity anomaly. Hence, in most cases little can be inferred about the "bedrock" itself. For this survey the geologic profiles of Plate 6 also made use of the aeromagnetic data in determining both structure and underlying rock types.

Profile AA"' (see Plate 6) for the most part follows U. S. Highway 50. Except for the westernmost 8,000 feet, the Section Λ "A"' was taken from Thompson (1959). Terrain corrections were added to Thompson's simple Bouguer anomaly at the six B.M.'s shown below the profile, and the resulting complete Bouguer anomaly plotted. Thompson's bedrock surface was also used except for the fault some 2 and 1/2 miles out in the valley. The presence of this fault is indicated by the change in the gravity gradient and also by a small aeromagnetic anomaly.

The greatest depth to bedrock along U. S. Highway 50 occurs just east of Frenchman Station and is estimated by Thompson to be about 5,600 feet. This places the floor of the valley at some 1,300 feet below sea level. Along both cross-sections the shape of the valley floor is interpreted as being caused by a combination of step-faulting and downwarping. Actually either could have produced the observed gravity pattern. Alternatively, if we assume that the density contrast is smaller near the margins than in the center of the basin - relatively dense gravels versus light playa silts - then the gravity data would permit a flat-bottomed graben. The profile. above, was considered to be the most reasonable geologically. The maximum gravity gradient encountered in Fairview Valley is about 3.8 mgal/kft. Following Bott and Smith (1958) the maximum depth to the top (bottom in this case) of the anomalous ass would be about 5,800 feet.

The rocks labeled "Tv" (a symbol not used on the geologic map, Plate 3) on the eastern end of both profiles, are the rhyolites and andesites of Fairview Peak. These partially metamorphosed volcanic pyroclastic and flow rocks are believed to be early Tertiary in age (D. Slemmons, oral communication). They have no definite correlatives in the QTv of the Sand Springs Range. There is a magnetic high of some 500 gammas over the eastern end of BB", but no corresponding high is present on the eastern end of AA". In fact, the magnetic level seems to be close to that found over the Sand Springs granites. Since the Tv rocks do not actually outcrop along this section of U. S. Highway 50 it is possible that this block should have been marked "gr" on cross section AA'.

The maximum depth to bedrock in Fairview Valley along B"B" is estimated to be 5,800 feet; this is some 200 feet deeper than along U. S. Highway 50. Again a fault basinward (one mile) from the Range front is postulated on both gravimetric and aeromagnetic evidence.

The surface geology across both the Sand Springs Range, BB", and across what might be better termed the southern end of the Stillwater Range, AA", is taken directly from the geologic map of Plate 3. The gravity high along the pestern margin of the Range is interpreted as having been produced by a section of metamorphic cooks which is 2,300 feet thick along section AA" north of U. S. Highway 50 and 1,100 feet thick west of Ground-Zero on line BB". These thicknesses were computed using

the assumed density contrast of 0.30 g/cc between the intrusive and metamorphic rocks. The metamorphic rocks outcrop but locally along AA". Even this is not the case along BB", or within several miles of it. However, it is possible that hydrology Test Hole H-3 did penetrate a thin section of metamorphics some 4,000 feet south of BB". (See the seismic section of this report.) H-3 is not on the gravity high itself, but 4,000 feet west on the flanks. The gravity data indicate that this postulated metamorphic section thins both vertically and horizontally southward from U. S. Highway 50 to just south of H-3. No estimate of the thickness of the metamorphic rocks in the southern portion of the Range was made because of the lack of gravity data over the top of the Range.

In the early part of this survey it was noted that the western side of the Range, east of Fourmile Flat, has considerably more topographic relief than the eastern side, without there being a corresponding steep gravity gradient. It is probable that the western side of the Range is bounded by a normal fault with a displacement of at least 2,100 feet - 1,000 feet of topographic relief and 1,100 feet of stratigraphic displacement involving the metamorphics. The down-thrown block simply did not drop enough to permit the extreme sedimentation which occurred in Fairview Valley.

The valley fill in Fourmile Flat is estimated to be a maximum of 1,300 feet thick on BB' and 1,000 feet thick on AA'. The QTv on the west end of BB"' are the basalts of the Cocoon Mountains. The QTv on the west end of AA"' are the basalts capping a spur of the Stillwater Range. The thicknesses of these basalt units are not known. From the magnetic map it is apparent that these more magnetic basalts do not extend appreciably basinward from their observed surface exposures.

The type of rocks immediately underlying Fourmile Flat is unknown. If they are dense metamorphics, then the valley fill is appreciably thicker than shown on Plate 6, depending on the thickness of the metamorphics. Thompson's estimate of 2,000 feet of alluvial fill along U. S. Highway 50 (AA') was made without first removing the gravitational effect of the metamorphics. Hence, his local gravity low over Fourmile Flat was appreciably greater than that used in calculating the 1,000 foot thickness given in this report.

Aeromagnetic Survey by James 1. Gimlett

INTRODUCTION

The primary purpose of the aeromagnetic survey, as originally proposed, was to delimit the granitic body of the Sand Springs Range both vertically and horizontally. In addition, the aeromagnetic data was expected to help resolve various geologic problems which might arise during the geologic and gravimetric mapping.

To accomplish the survey a 20 mile square (Area A) was flown at a half-mile spacing. The terrain clearance was as close to 500 feet as was consistent with aircraft safety. As flown, the area was covered by 39 E-W profiles and 4 N-S cross profiles. Plate 7 is the aeromagnetic data contoured on a 50 gamma interval. The aircraft flight paths and the spotted photo-centers are shown.

Because the aeromagnetic coverage was completed much later than had been planned, many of the items necessary for a detailed interpretation were not available prior to the writing of this report. Only the original aeromagnetometer tapes and a hurriedly-prepared pencil contour sheet were available. Therefore, the interpretation section following should be considered as preliminary as well as sketchy. If the examination of all of the aeromagnetic data reveals any features important to the project, a supplementary report will be submitted.

INTERPRETATION

Many of the rock units used in the geologic mapping can be identified by their characteristic "grain" on the aeromagnetic map, Plate 7.

The granitic rocks of the Sand Springs Range evidently have fairly low magnetic susceptibilities. The magnetic level is low, but all profiles show quite a bit of magnetic relief over the top of the Range. This irregularity of magnetic relief is a common feature over intrusives. The reason usually given is that the magnetic minerals tend to congregate in clots, i.e. the mixing is not complete. However, in this case the irregularity is, at least in part, the affect of both topography and structure.

Both Fairview Valley and Fourmile Flat are marked by magnetic surfaces of low relief and at low magnetic levels. This would indicate that the valley-fill deposits have much lower susceptibilities than the surrounding rocks and that they must either be very thick, or must overlie other essentially nonmagnetic rocks.

There is a smooth magnetic high over the southern end of the Range. This would indicate a rather homogeneous rock whose susceptibility is somewhat greater than that of the granite. This anomaly is interpreted as being due to the metamorphic rocks, which are predominantly phyllite-hornfels in this area. The Quaternary-Tertiary volcanic cover in this area consists mostly of rhyolitic flows and pyroclastics. It is too thin, and the rocks are too nearly nonmagnetic, to affect materially the magnetic pattern.

The metamorphics on the north end of the Range are in an area which is geologically complex, involving contact effects, mineralization, and QTv intrusives and extrusives in addition to the metamorphics. As a result, no magnetic anomalies can be definitely attributed to the metamorphics alone.

The baselts of the Cocoon Range and the southern Stillwater Range produce a fairly typical magnetic pattern - very rough magnetic topography, having large anomalies (up to 1,300 gammas relief) with the lows being more conspicuous than the highs. These lows are not due to the simple geometric

response to the inclined magnetic field, whereby there is a magnetic low on the north side of every high. Generally these prominent lows are ascribed to edge effects and/or to reversed polarization. The basalts, as to be expected, have greater susceptibilities than do the granites or metamorphics.

There are several large anomalies over Fairview Peak, in fact much larger than would be guessed from the "Tv" specimens examined. The largest anomaly (900 gammas) detected during this survey is over Slate Mountain, which is in the southeast corner of Area A. (See Plate 7.) No attempt will be made to explain these features as they are outside the area of prime interest.

The magnetic data helped to explain several features considered in the gravity section of this report. For instance, either the basalts on the south, west, and north sides of Fourmile Flat do not extend into the basin, or if they do, they are flows too thin to have much magnetic expression. The presence of the faults in Fairview Valley away from the Range front (see Plate 6) is based in part on small (several gamma) magnetic anomalies. The gravity "nose", extending out into Fairview Valley south of Lucky Boy Canyon coincides with a magnetic high. Taking into account the fact that the rocks producing this anomaly are buried beneath valley fill, the magnetic level here is greater than that over the granites to the north. Hence, it appears that these rocks have greater susceptibilities than do the granites. Thus, the gravity and magnetic anomalies are interpreted as having been produced by a horst composed, at least in part, of metamorphics.

The limits of the surface exposures of the granite can easily be seen on the aeromagnetic map. The northern contact of the granite with the metamorphics is marked for its entire length by a prominent magnetic low, which is probably due to the geometric effect as well as to contact effects, hydrothermal alteration, etc. On the south the typical granite pattern abuts the large magnetic high over the metamorphics. It is impossible to determine magnetometrically the extent of the granite to the north and south of its surface exposure because of the masking effect of the overlying rocks.

A fair fit to the magnetic profiles across the granitic portion of the Sand Springs Range can be obtained by using a simple, flat-topped horst with vertical sides as an analytical model. Making a reasonable estimate as to the altitude of the aircraft (the altimeter tapes are not yet available), 5,700 feet was found as the maximum depth of fill in Fairview Valley. This is within 100 feet of the depth obtained in the gravity survey. The agreement is remarkable in view of the assumptions involved in both methods.

A depth of 2,500 feet was obtained in Fourmile Flat. This is greater than the gravimetrically determined depth, though it might be noted that 1,000 feet of valley fill plus 1,500 feet of metamorphosed sediments should be the magnetic equivalent of 2,500 feet of valley fill.

The calculated magnetic susceptibility (average of three determinations) is $1,400 \times 10^{-6}$ c.g.s. Assuming that the susceptibility of the granites depends (linearly) only on the magnetic content, we find that the granites should contain on the average 0.28 percent magnetite.

It was originally planned to have susceptibility and remnant magnetism measurements made on some 30 samples taken from widely separated points in Area A, and from the drill cores. This was not done because of the delay in obtaining aeromagnetic coverage and the delays in drilling. At the present time it is planned to make these measurements only on the core from ECH-D. They are not intended to help with the aeromagnetic interpretation but rather to augment the before-the-blast catalog of the physical properties of the granite.

Refraction Survey by James I. Gimlett

INTRODUCTION

It was apparent that several geological-geophysical problems might best be solved by seismic methods. Preliminary analysis of the gravity data indicated that the valley fill was very shallow in Fourmile Flat immediately west of the Sand Springs Range, and very deep in Fairview Valley to the east. It was also evident that the east side of the Range was bounded by steep, normal faults. The refraction survey was designed to serve as a check on, and to augment the gravity and aeromagnetic data.

The refraction method could be expected to provide accurate depth-of-fill data on the west. Also, it should be possible to determine something of the dip of bounding faults on the east by shooting in the high speed granites and by shooting a parallel series of profiles broadside to the Range. Although the third problem, the depth to "bedrock" in Fairview Valley, is made to order for the reflection method, the costs for drilling the shot holes were deemed too high, hence no reflection survey was planned. (It has been found both in this area and elsewhere, that to insure the transfer to the ground of an amount of elastic energy sufficient to produce strong reflections it is required that the shot be emplaced below the water table. The water table in the Fairview Valley opposite Ground-Zero is fairly deep, near 300 feet, and the ground is in such condition that the shot-holes would have to be cased.)

Some preliminary testing was done in the granitic mass on top of the Sand Springs Range with a DynaMetric seismic time, because it was thought that the velocities obtained would be useful in later refraction surveys. However, the velocities determined using this "Flintstone" system were only about one half of those determined using an explosive energy source, a phenomenon also observed elsewhere. Also, using this system, calculated depths have been found to be less. The hammer impulses probably excite only the near-surface weathered material, not the deeper, more massive rock.

EQUIPMENT AND DRILLING

The refraction seismograph unit used to carry out this program was a 12-channel research model. The University of Nevada is especially indebted to Professor J. L. Sosle of Stanford, who, in addition to furnishing the seismograph, also donated four days field time to the project.

A PRINCE OF THE PARTY OF THE PA

The shot-hole drilling was contracted to Sprout Engineers, Inc. Eighteen holes (9 on each side of the Range for Profiles I and III, Plate 6) were drilled without difficulty in granite, 6 each at 5, 10, and 15 foot depths. The holes in the valley fill, drilled with a power auger, proved to be more troublesome. All of these holes were cased with galvanized drain pipe to prevent caving. This worked well on the west side, but on the east side where the alluvial debris is much coarser, all of the holes except for the top 5 feet were lost as the drill was removed. The two holes for Profile II were hand dug to a depth of 4 feet with a shovel. They proved satisfactory.

Atlas 60 percent and 40 percent "Gelodyn" blasting gelatines fired by "Static master" caps were used as the explosives. In practice the sticks were slit and tamped in the holes.

PROFILES

Three east-west refraction profiles were shot and are shown on Plate 6. The location for refraction Profile I was selected on the basis of the very low gravity gradient encountered on Gravity Line 14, which is some 150 feet to the north of I. In fact there is less than one mgal variation on this line over its entire two-mile length.

Profile I consists of three 2,400-foot spreads (200 foot takeouts). Most of the pertinent data for the entire profile are given on Figure 3 which shows the time-distance curves for the westernmost of the three spreads. The calculated depth to the high velocity medium is only 176 feet at the center of this spread, which is 5,600 feet from any granite exposures in the Range.

The average velocity of the high-speed medium as determined from the shots emplaced in the granite is about 11,500 ft/scc. This is fairly typical for weathered granite or metamorphics. The low velocity is on the order of only 2,000 ft/sec, indicating that the valley fill-debris is unconsolidated in this area.

Profile II, consisting of one 2,400-foot spread, is centered at hydrology test hole H-3. The refraction data, shown in Figure 4, indicate that the high-velocity medium dips gently to the west at 1.2°. The depth to this medium at H-3 is 196 ft. The low velocity, encountered on II, is much the same as on Profile I. The high velocity, 13,810 ft/sec, is 2,300 ft/sec higher.

Unfortunately, the seismically determined depth (196 ft.), does not agree with the depth (310 ft.) shown on the well log of H-3 (see Appendix E). A possible explanation for this difference is as follows: the well log shows lithic fragments in the interval 140 to 205 feet. These rocks are reportedly metamorphic. In view of the fact that H-3 does not lie down drainage from any present metamorphic outcrops, it is postulated that the drill penetrated 114 feet of weathered metamorphic before entering the granite.

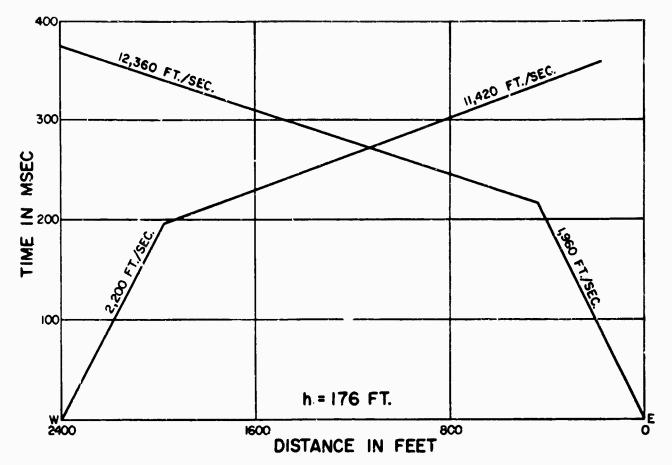


Figure 3. Ti e-distance curves, spread 3, Profile I

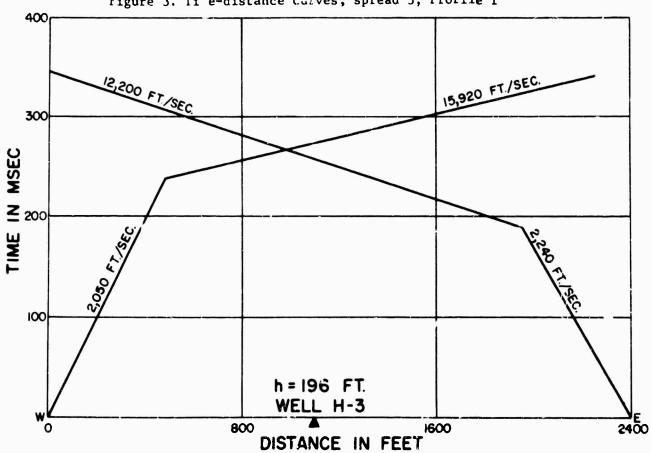


Figure 4. Time-distance curves, Profile II

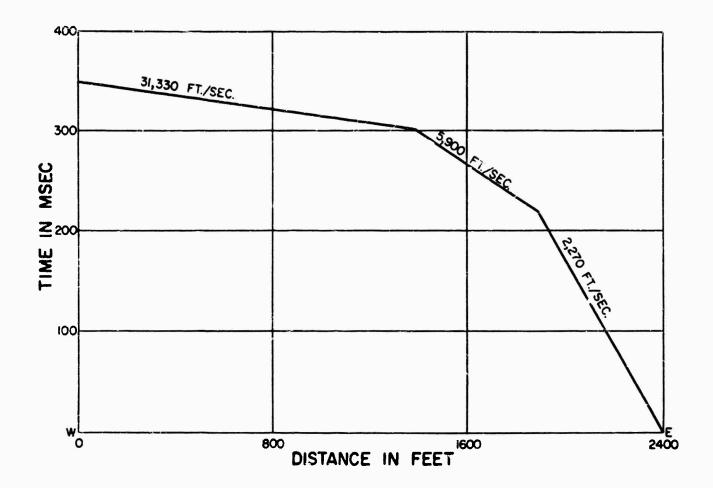


Figure 5. Time-distance curve, spread 1, Profile III

The drilling rate in the metamorphics could be expected to be greater than in the granites. The granites, valley-fill, and some of the schists and argillites of the metamorphic section are quite similar mineralogically. Hence, it is possible that the interface between the valley fill and the assumed metamorphics was not recognized during the drilling. As mentioned in the gravity section of this report, well H-3 lies just off the axis of a gravity high which might best be interpreted as being produced by buried metamorphics.

Profile III, two 2,400 foot spreads, is just south of and parallel to the GZ Canyon road. The time-distance curve for the shot into the Range on spread I is shown in Figure 5. No recognizable events were recorded on the shot out of the Range, i.e. with the shotpoint in the granite. (This is also the case for spread 1 of Profile I). This is a fairly common occurrence (J. L. Soske, oral communication) when shooting from a high-speed into a low-speed medium. From surface evidence the frontal fault should intersect spread I at about the 1,100-foot mark of Figure 5.

The highest velocity found on spread 2 was 7,870 ft/sec. Energy traveling at this velocity was recorded for all three shots, one at each end of the spread and one in the granite 2,400 feet west of the westernmost geopnone. This velocity is too low for the medium to be granite; it is more likely to be compacted fill. The top of this high-velocity medium closely coincides with the water table as measured in hydrology test hole HS-1. The depth to a granite or metamorphic bedrock would have to be greater than 2,000 feet, as no higher velocity returns were recorded 4,800 feet out from the shotpoint.

No profiles were shot parallel to the Range, it being felt that with the gravity and aeromagnetic surveys sufficient data were already at hand for the purposes of this project. Furthermore, it is anticipated that more refraction work will be done in Fairview Valley at the time of some proposed he shots of the U.S.G.S. and at the same time as the Shoal event. With the large energies involved it should be possible to obtain a depth figure for the bottom of Fairview Valley.

Physical Properties of the Drill Core by Robert C. Horton

Tests were made of the thermal conductivity, permeability, and elastic properties of the granitic drill core from drill hole ECH-D. It was not expected that extreme variations would be found, thus the physical properties mentioned above were measured on segments of core taken at approximately 500 foot intervals. The results of the tests supported this expectation.

THERMAL CONDUCTIVITY

The thermal conductivity determinations were made using equipment constructed in the laboratory of the Nevada Bureau of Mines. A small hot plate, with a "variac" to control the current, was used as a heat source. Each core segment, 2 centimeters thick with a cross-section area of 80.1 square centimeters, was sandwiched between 3/16-inch-thick brass disks. This assembly was placed in an aluminum foil basket resting in a sand bath heated by the hot plate. The sand bath, aluminum foil basket, and brass disks acted to provide an even distribution of the heat. A 500 ml. Erlenmeyer flask was placed on top of the upper brass disk. The foil basket was then filled with pulverized calcined diatomite, completely covering and surrounding the core segment, brass disks, and Erlenmeyer flask, thus insulating the entire assembly against heat loss or undesired heat flow.

Two thermocouples were attached to the bottom of the core segment and two attached to the top. One top-bottom pair was connected in a differential circuit with a recording potentiometer to measure and record the difference in temperature between the top and bottom thermocouples. The other two thermocouples were connected to a sensitive potentiometer to measure the absolute temperatures of the top and bottom of the core - the hot and cold sides. To determine the thermal conductivity of a core segment, the hot plate was turned on and water allowed to flow through the Erlenmeyer flask from a steady-head supply. The water was introduced at the bottom of the flask through a glass tube and removed at the top. The temperature of the incoming water was measured with a mercury thermometer mounted in the steady-head supply, and the remperature of the discharge water was measured with a mercury thermometer mounted in the top of the Erlenmeyer flask, immediately adjacent to the outlet.

Measurements were begun when the recording potentiometer indicated that a constant temperature difference had been established between the hot and cold sides of the core segment. A graduated cylinder was placed under the water discharge, the temperatures of the water at the steady-head and flask outlet were recorded, and the temperatures of the hot and cold sides of the core were recorded. The discharge water was collected for 15 to 40 minutes, the temperature readings were repeated at the end of the time period and averaged with the first readings. Knowledge of both the volume of water collected in the graduated cylinder, and the increase in temperature from inlet to outlet permitted calculating the calories of heat transferred during the time period. The temperature readings of the hot and cold sides of the core segment established the average temperature gradient. These readings rarely varied more than 0.5 degree Celsius from

the average, and were usually within 0.2 degree Celsius of the average. A temperature gradient of 40 degrees Celsius was usually maintained, with the lower temperature being about 90 degrees Celsius.

The above procedure was repeated until consistent results were obtained, further indicating the establishment of balanced conditions. Many of the observations were made during a 30 minute time period during which time over 750 ml. of water were collected, a volume 1.5 times the volume of the Erlenmeyer flask. The results of the testing are given in Table 2. These results compare with values of 0.0054 to 0.0059 gram calories per second per degree Centigrade per centimeter given for granites in Geological Society of America Special Paper 36, page 849. The slightly lower results obtained for the cc a segments are probably caused by the thermal resistance of the fracture cleavage.

MODULUS OF ELASTICITY

The modulus of elasticity (Young's modulus) was determined using a compression tester with a capacity of 250,000 pounds. The pressure gauge was tested using a proving ring certified by the National Bureau of Standards. Strain measurements were made using a feeler gauge with 0.0005 inch divisions. Readings could be made to 0.0001 inches with an accuracy of 0.0001 inches. Total deflections exceeded 0.0150 inches when a compressive load of 120,000 pounds was applied.

Segments of granitic core approximately 7 inches long by 4 inches in diameter were tested. The cores were brained from drill hole ECH-D at depths of approximately 512 feet, 994 feet, 1,422 feet, and 2,004 feet. Each core was compressed with a maximum total load of 120,000 pounds, the pressure slowly released, recompressed to 120,000 pounds, and the pressure again slowly released. Strain readings were taken at 2,000 pound intervals for the 0 to 20,000 pound load range, and at 10,000 pound intervals for the 20,000 to 120,000 pound load range. Two hysteresis curves were constructed for each core and are shown in Figures 6 to 9.

The values obtained for the modulus of elasticity (Young's modulus) are given in Table 2. The uneven values for the compression loads are a result of dividing total leads of 20,000 and 120,000 pounds by the area of the core. The modulus of elasticity for any particular interval in the range 0 to 10,000 p.s.i. may be determined by using the proper hysteresis curve.

The values obtained for the modulus of elasticity compare with values of 3,440,000 p.s.i. to 8,280,000 p.s.i. for surface specimens of granite; and values of 5,000,000 p.s.i. to 6,820,000 p.s.i. obtained for granite at a depth of 235 feet as given in Geological Society of America Special Paper 36, page 73.

PERMEABILITY

Tests to determine the permeability of the core were made by Core Labs, Inc., Dallas, Texas. Core segments from depths of approximately 512 feet.

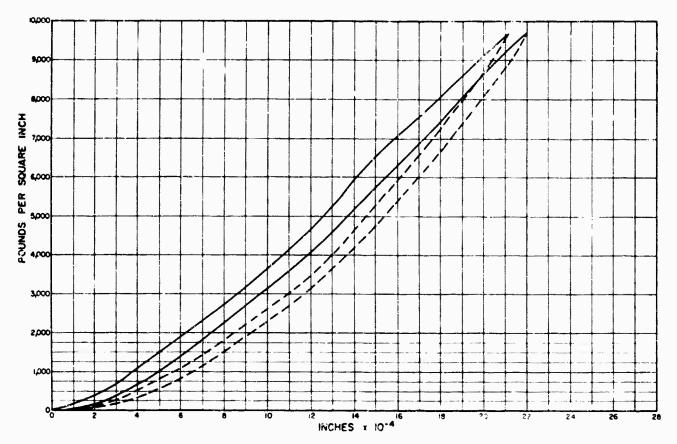


Figure 6. Stress-strain hysteresis load curves, core segment of granite at 512 feet in Core Hole ECH-D.

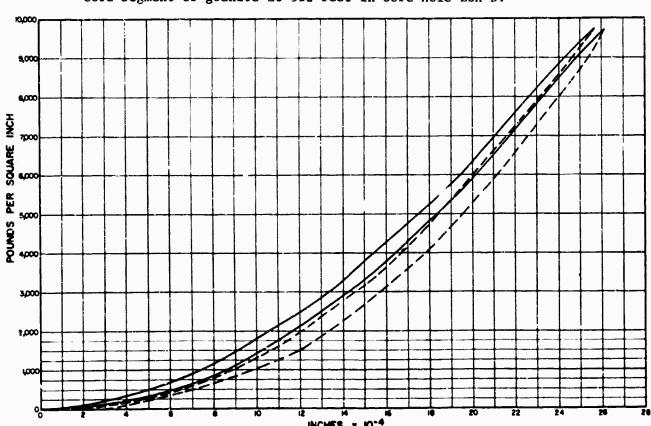


Figure 7. Stress-strain hysteresis load curvescore segment of granite at 995 feet in Core Hole ECH-D.

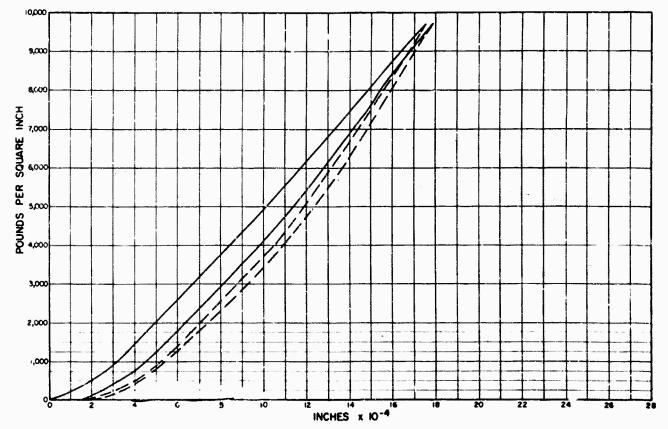


Figure 8. Stress-strain hysteresis load curves core segment of granite at 1422 feet in Core Hole ECH-D.

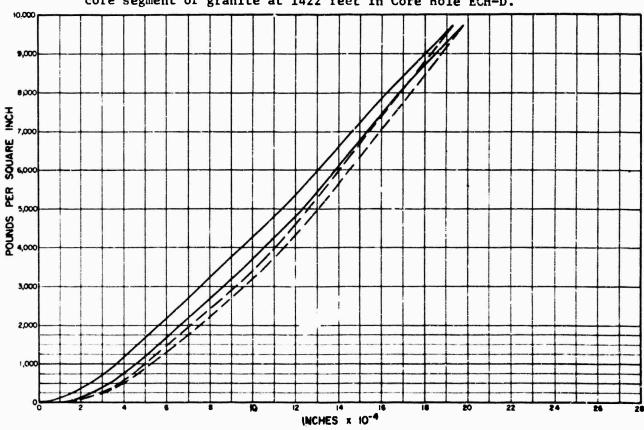


Figure 9. Stress-strain hysteresis load curves, core segment of granite at 2003 feet in Core Hole ECH-D.

994 feet, 1,422 feet, and 2,004 feet were tested. The results are given in Table 2. Permeability tests of granite are rarely made and no reliable figures for general ranges of permeability in granite could be found. The permeability is extremely low, being 1/1,000 to 1/1,000,000 of the low range for permeability in sedimentary rocks.

The permeability values were measured while the whole-core samples were subjected to simulated overburden pressure. The overburden pressure was simulated by establishing a pressure differential of approximately 0.6 p.s.i. per foot of depth between the external and average internal pressure applied to the core.

GENERAL OBSERVATIONS

The values obtained for the physical properties appear to be of the proper magnitude. A comparison of the various physical properties of individual cores reveals substantiatin agreement. As an example, the core with the lowest thermal conductivity also has the highest permeability. while the core with the highest thermal conductivity has the lowest permeability. This is to be expected because the permeability represents, in a general way, the number of openings or discontinuity of solid rock with the core, while the thermal conductivity represents a continuity of a 13 structure. The same relationship is apparent when mparing the permetbility and the modulus of elasticity. The specimen with the highest modulus of elasticity has the lowest permeability and the converse is also true. A definite relationship exists between the modulus of elasticity and the thermal conductivity. If the modulus of elasticity is plotted against the thermal conductivity for the four core segments, a straight 1200 will result, with the exception of the core segment taken at a depth of 994 feet. It thus appears that either the thermal conductivity or the modulus of elasticity may be readily determined if one value is known, and if the core has not somehow been altered or disturbed.

In the case of the core segment taken at 994 feet, visible cracks were apparent following determination of the modulus of elasticity. A few loud audible cracking sounds were heard during testing. The visible cracks are parallel to the axis of the core. No changes were noted in the other cores during or following testing. The low initial modulus of elasticity for this core, as compared to the others, suggests the presence of openings. As the modulus of elasticity for the high range is normal, these openings may have closed during the early stages of compression. The presence of minute openings is further suggested by the higher permeability and lower thermal conductivity.

The results of the testing on the core segment obtained at 994 feet should not be extrapolated throughout a large interval. The cores for physical testing were selected so that they would be as solid as possible and free from any apparent fractures or cracks. Testing of core with obvious flaws would yield little or no valuable information.

Other portions of this report describe the condition of the core throughout the length of hole ECH-D. The values obtained during the

physical testing can be applied to the intervals where solid core without fracture or faulting was obtained. Segments of core 30 disturbed will have lower moduli of elasticity, high permesbilities, and probably lower thermal conductivities. The presence of water will obviously alter the thermal conductivity.

TABLE 2

Core Depth	Young's Mod		Thermal Conductivity	Permeability
(Feet)	Range (p.s.i.) 0-1618	Range (p.s.i.) 1618-9708	Gram calories per sec. per cm.x10 ⁻³ 4 100°C	Millidarcies x 10 ⁻⁶
512	3,000,000 * 2,900,000	5,090,000 5,180,000	3.6	13.6
994	1,700,000 1,760,000	5,030,000 5,180,000	3.1	3,100
1,422	3,860,000 * 3,860,000	6,160,000 6,730,000	4.5	less than 1
2,004	3,410,000 3,510,000	5,680,000 5,910,000	4.1	390

^{*}The upper figure is derived from the first hysteresis compression curve; the lower figure from the second hysteresis compression curve.

HYDROGEOLOGY AND HYDROLOGY

By

George B. Maxey, Patrick A. Domenico and David A. Stephenson

Nature of the Problem

The purpose of this investigation is to determine the probability of contamination of water as a result of the proposed nuclear detonation in the granitic mass in the Sand Springs Range. In order to reliably predict the probability of contamination, it is necessary to ascertain the origin of the water, its rate and direction of movement, and the location of all points where water is removed from the system, either naturally or artificially. Further, as the study deals primarily with ground water, the geologic nature of the transmitting media assumes critical importance. This report, therefore, records evidence obtained from both hydrologic and geologic studies as they pertain to the occurrence and movement of water, and interprets this evidence in regard to the probability of ground-water contamination. Preliminary considerations indicated that the study might safely be confined to within a 15-mile radius of the proposed experiment and detailed studies here reported are so treated. Supplementary observations beyond this limit are included where justified by special considerations, such as present or potential water use and population density.

Summary of Drilling and Testing Program

At the outset it was recognized that available hydrogeologic and hydrologic data were sparse and inadequate for the purposes of the investigation. Further, sources of hydrologic data such as existing wells and springs were similarly limited. Therefore, a modest test-well drilling program was initiated to obtain information on the occurrence and nature of the geologic formations, their hydraulic characteristics, and on the occurrence, movement, storage, and chemical quality of the water.

On February 14, 1962, two cable-tool drill rigs started operations on Test Holes HS-1 and H-4 in Fairview Valley. The test holes were located 150 feet apart in Section 32, T. 16 N., R. 33 E. (see Figure 10 and Table 3). The holes were intended to be drilled and tested simultaneously, but when the lower boundary of the first aquifer system was encountered and the first pumping tests had been conducted, it seemed expedient to continue exploration in one hole only, and to move the other drill rig to a new location. Accordingly, operations were started on Test Hole H-3 in Section 29, T. 16 N., R. 32 E. in Fourmile Flat on March 16. Drilling was meanwhile continued in Test Hole H-4, and it was planned to deepen Test Hole HS-1 with the same drill rig as soon as results of exploratory drilling in Test Hole H-4 indicated the most logical program to follow. Similarly, the drilling operation at Test Hole H-3 was to guide further drilling in Fourmile Flat, specfically to determine the need for a nearby observation well. Following this plan, Test Hole H-4 was completed at 935 feet and the drill rig was moved to Test Hole HS-1, which hole was subsequently completed at 699 feet.

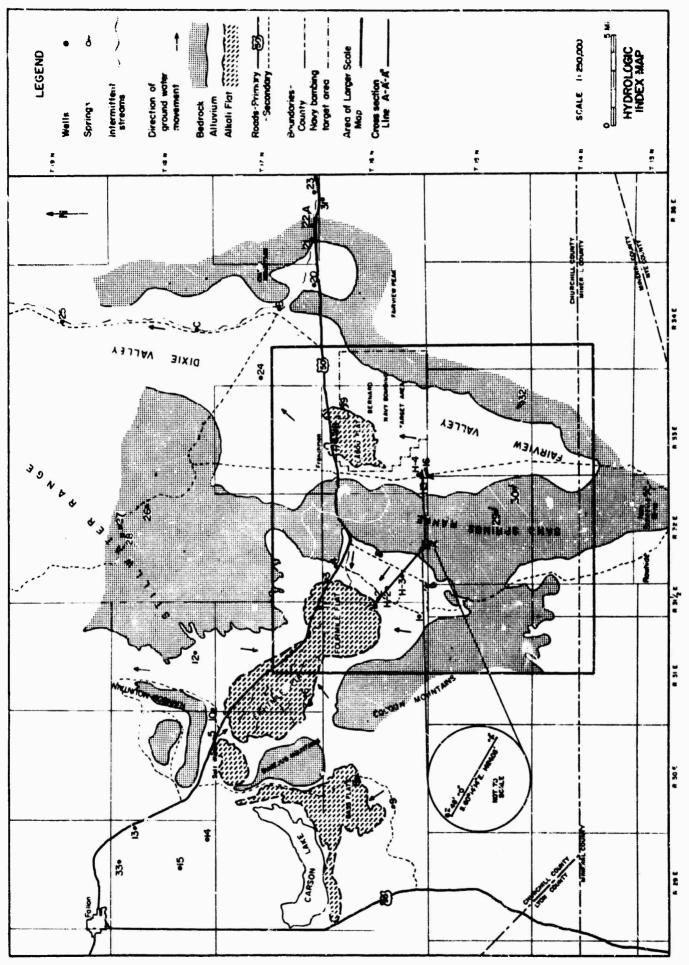


Figure 10

TABLE 3. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHUKCHILL COUNTY, NEVADA

			8	- Feet	in inches	in gom (eat.)	Type	Elevation	å	Depth to Water	Remarks
HS-1	sec. 32 T16N	A. F. C.	Yell Kell	669	œ	70	Turbine	4243.76	2/17	300.14	Shoal Project Test Well
T	Sec.	A. E. C.	Test Well	935	9	70	Submersible	4241.92	2/18	299.2	Shoal Project Test Well
H-2	5E% sec. T16N R3	A. E. C.	Test Well	768	% %	%	Reda	4017.3	7/30	110.88	Purpo removed
H-3	3	F. C.	Test Well	480	% 80	5 - 10	Peerless	4232.2	7/31	328 3	Pump removed
-	2	P. Cushman	Dom.	315	9	5 - 10	Cylinder	4192.7	1/9	285.0	Gas driven
8	7% Sec 16N 93	P. Cushman	Stock	•	4	3 - 5	None	3900	1/9	G.S.	Flowing, water leak near casing
က		P. Cushman	Stock	27	9	0.5 - 1	None	3904.5	4/10	3.19	Gravity feed to
4	Sec. 5 TI6N R32E	F. Bennett	Aband.	162	9	:	None	3973.6	7/30	65.2 65.87	Tueasten Nill
E)		B. Matthews	& Com.	•	Ś	20 - 25	Submersible	3961	4/13	29.1 29.25	Big Top Restaurant
9	Sec. 31 TIZN R315	Whitman	Stock	•	9	0.5 - 1	None	3928	7/30	1.3	Gravity feed to
7	SWA NEW NWW sec 31 TITM R316	Whitman	Stock		9	0.5 - 1	Nose	3933	4/16	+2+21	Flowing Well
∞	SWN Sec. 9 T16N 830E	R. Bass	Stock		0	1.2	Cylinder	3990*	4/17	21.45	Wincmill
٥	SW14 sec. 20 T16N R30E	R. Bass	Stock	1	9	10 - 15	Cylinder	3990*			Gas driven
0	SW1/2 SW1/2 SW1/2 sec. 31 T18N R31E		Stock	300	*	0.5 - 1	Cylinder	3976	4/13	32.4	Windmut
=	NW% sec. 6 T16N R32E	Cons. Co.	None	8-	.4		None	3893.4	5/22	7	Flow ociavel
12	SW1/4 Sec. 27		Stock	350	9	0.5 - 1	Cylinder	4226	5/29	300	Windmill
13	SE% sec. 12 T18N R29E	H. Pierce	Dom.	7	12 ft.	3 - 5	Gas Driven	3919.6	5/22		Water level influenced by irrigation returns
4	NE% sec. 35 T18N R29E	P. Schaffer	Stock	80	4.5	0.5 - 1	None	39.77.6	5/25	+3	Flowing west

TALLE 3 (Continued). WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

Well	Locations	Owner	80	Depth In Fest	Diameter, in Inches	Discharge in gpm (est.)	Pump	Surface Elevation	8	Date and Depth to Water	Romarks
15	Ŋ. F	S. Flippen	Dom.		•	1.2		3907.6	5/26	+2	Flowing well
16	SE¼ SE¼ SW¼ sec. 32 T16N R33E	6	Stock	364	9	ഗ	Cylinder	4262.78	4/17	319.20 319.28	Windmill
17	SW1/2 SE1/2 NW1/4 sec. 3 T16N R33E	Ed Weyher	Dog.	230	•	55	Submersible	4153.3	4/17	224.10	At rear of garage
8	SW1/2 SE1/2 NW1/4 sec. 3 T16N R33E	l	<u>Б</u>	288	&	17	Submersible	4153.3	4/17	224.60	In wood crib in pasture
19	NEW NWW NEW sec. 11 T16N R33E		to Pes	373	∞	5	Cylinder	4147.80	7/10 4/23	218.84 218.80	On bombing range
20	SE¼ sec. 35 T17N R34E	State	to Pos	3.5	&	None	None	4386	7/10 4/16	266.16 266.16	In Stingaree Valley
21	SE14 sec. 32 T17N R35E	State	P &	110	9	None	None	4468	2//4 2/17	53.87 72.00	At old 3-C Camp
22	SW% sec. 33 T17N R35E	B. F. M.	Stock	51	9	02	(·)der	4518	7/10 4/10	i	At Westgate large tank
23	NEW SWW SEW sec. 34 T17N R35E		<u>=</u>	(Rep.) 202	01	1000	Turbine	4615	7/10	93.00 92.35	At ranch at Middlegate
24	SW1/4 sec. 18 T17N R34E	B. L. M.	Stock	334	9	01	Cylinder	4217	01/7-	279.20	In north flats, tenant C. B. Stark
25	NE% sec. 21 T19N R34E	B. L. M.	Stock	33.5	9	2	Cylinder	3814	7/10	278.29 292.40	Hot well, tenant C. B. Starl
26	NW% sec. 13 T18N "32E	H. Kent	Stock	99	25 ft.	None	Piston	5500*	9/9	99	Bulldozed sump
27	SW% sec. 2 T18N R32E	H. Kent	Stock	80	9	01	Cylinder	2600*	9/9	14.2	Well at corrai
28	SE% sec. 3 T18N R32E	H. Ken	Stock	(Rep.)	9	10	Cylinder	\$600	9/9	25.9	Windmill
29	SW'/4 sec. 23 T15N R32E	B. L. M.	Stock	က	3 ff.	٥	Siphon	550n*	Spring		Frenchman Spring
30	NW% sec. 36 T15N R32E	B. L. M.	Ps&U	Land	- #.	Very Small	None	5200	7/3	Seep	In Ram's Head Canyon
3.	Z Z	Malendy	D			0		4150*			Middlecate S. Station
32	SE% NW% sec. 35 T15N R33E	B. L. M.	Stock	ю	3 #.	Small	None	5500*	2 9/2	Spring	Slate Mountain Spring
33	NE% sec. 3 T18N R29E	F. Soars	Dom.	18 - 20				3934*	5,22	80	Water level poss. infl. by irrig.
						*Estimated					

In Fourmile Flat, Test Hole H-3 was drilled to a depth of 480 feet. Because granitic bedrock of very low permeability was penetrated below the water table, and pumping tests in this area could not be successfully conducted, it was concluded that drilling an observation well at this location was not justified. Therefore, the drill rig was moved to a new site in Section 19, T. 16 N., R. 32 E. and Test Hole H-2 was drilled. This hole was completed at a depth of 768 feet in alluvial sediments.

Pumping and bailing tests at the Fairview Valley site were conducted both during drilling operations and after the wells were completed. One pumping test was run when both Test Hole H-4 and Test Hole HS-1 were at a depth of about 530 feet, at the top of the first clayey layer encountered. The second pumping test was conducted following the completion of both holes, when the lower aquifer was pumped and the upper aquifer was sealed off, at least in the pumping well. In addition, at Frenchman, farther north in Fairview Valley, well3 which are 280 and 288 feet deep (Wells 17 and 18) were tested.

Pumping tests in Pourmile Flat were conducted after each test hole was completed. At Test Hole H-3 extensive bailing tests were run to determine whether a pump should be installed. Since these tests were inconclusive, a pump was installed and a conventional one-well test was conducted.

A series of recovery tests were per ormed on ECH-D, the vertical granite test hole near Ground-Zero. These consisted of bailing and blowing out the hole and observing water-level recovery when the well had been drilled to a depth of 1,355 feet, and again when the well had been drilled to a depth of 1,575 feet.

Gamma ray, neutron, and temperature logs were run in Test Holes H-4 and H-3, and samples for chemical analysis, tritium content determination, and radiometric analysis were taken from the test holes. The results of most of these analyses are given in a subsequent section of the report.

The information derived from the drilling and testing program is described in detail in the following parts of this report and in Appendices C through G.

Hydrogeology

Water occurs at the surface in a few places and at varying depths underground throughout the area. In nearly all instances ground water is found shallower in the valleys and deeper in the mountains, although a few seeps and springs in the Sand Springs and Stillwater Ranges and on Fairview Peak-Slate Mountain attest to the presence of some shallow, probably small bodies of perched or otherwise trapped water. Evidence from drilling operations in the Sand Springs Range granite is essentially inconclusive regarding the water-bearing characteristics of such rock, although it has been established that some water does occur in the granite. Continued study of this

Public Health Service.

¹The results of tritium studies had not been received at publication date.

²Radiometric analysis has been conducted and will be reported by the U.S.

problem is anticipated. The detailed geology of the consolidated rocks of the Sand Springs Range is given in the Geology section of this report. Consolidated rocks of other ranges bordering the valleys have been examined by reconnaissance only, in order to determine their hydrologic significance. The consolidated rocks act as geohydrologic barriers and neither store nor transmit appreciable quantities of water - appreciable, at least, in relation to any probable contamination hazard that might occur as the result of the Shoal experiment. Therefore, the emphasis in the hydrogeologic study has been placed on investigation of the valley fill, because these sediments do contain and transmit appreciable quantities of water and form the reservoirs from which water supplies are withdrawn.

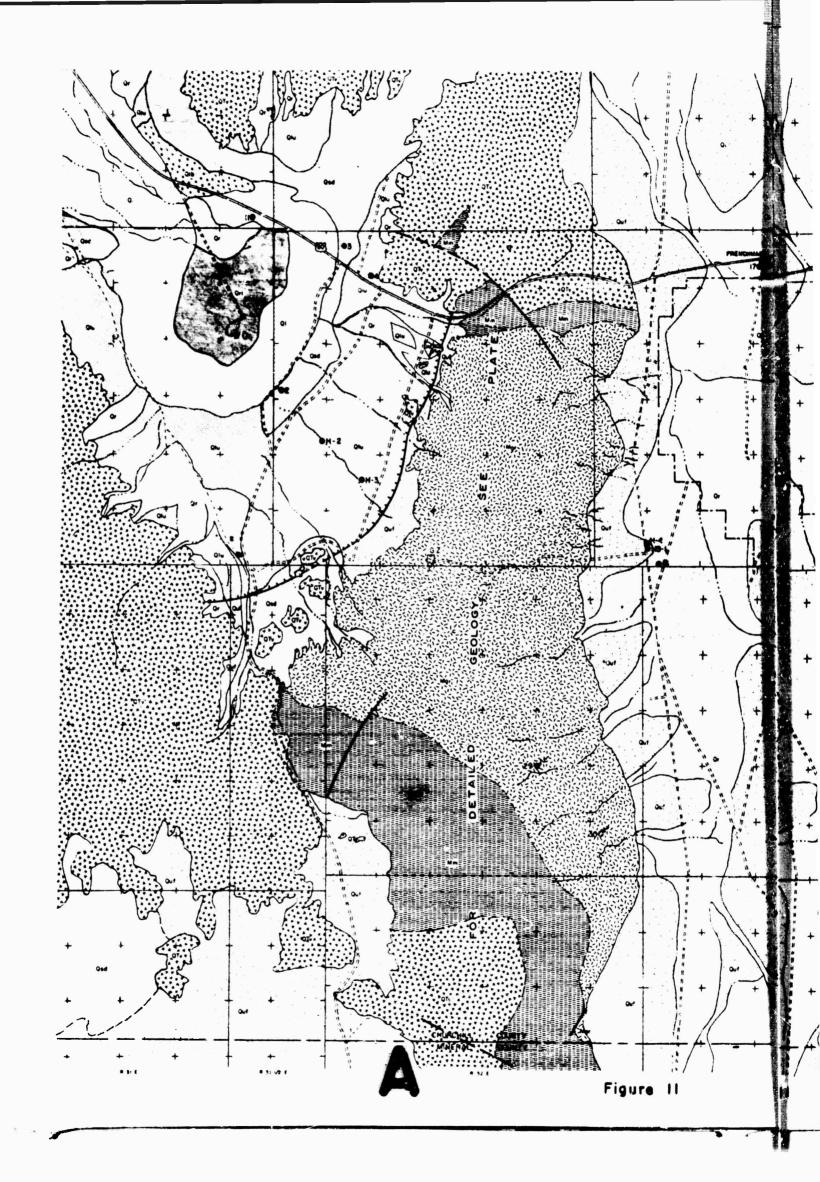
GEOLOGY OF THE VALLEY FILL

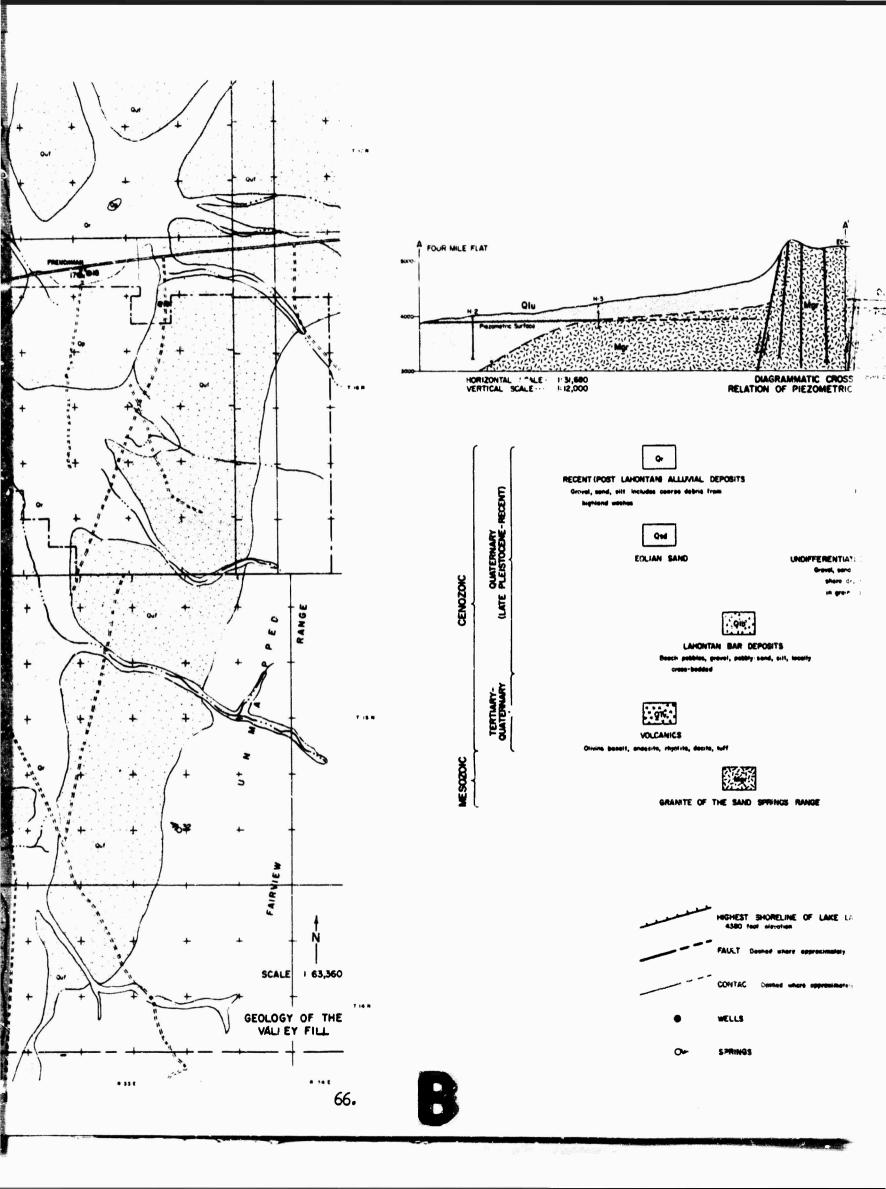
Figure 11 is a geologic map of the valley fill in the area included within roughly a 15-mile radius of Ground-Zero. Figure 10 shows geologic features outside this area that are of critical importance to the hydrogeologic and hydrologic problems. As is shown on the maps, the the areas containing widespread deposits of valley fill are Fairview Valley and the valley in which Fourmile and Eightmile Flats occur.

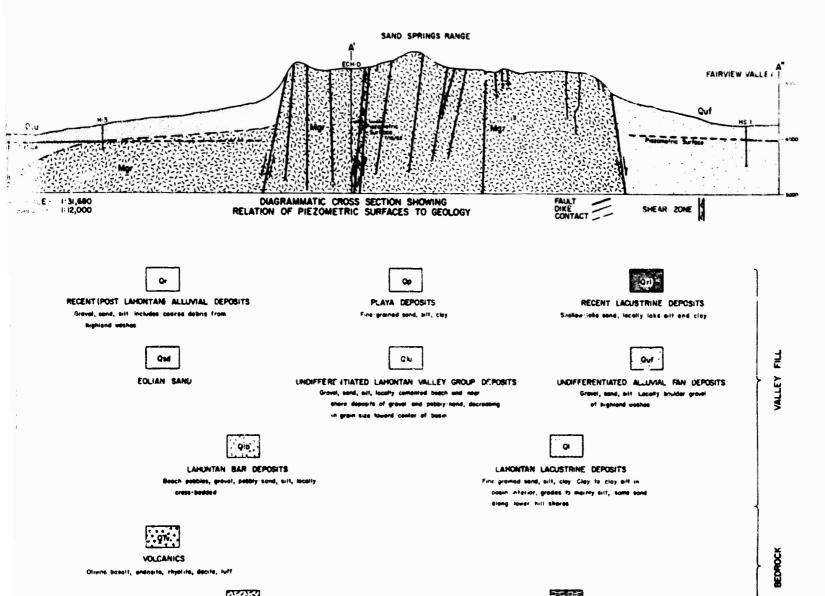
Fairview Valley

Fairview Valley is a structural bedrock basin which has been partly filled with alluvial sediments. Gravity studies, previously discussed, indicate that consolidated rocks are at least 5,800 feet deep near the west side of the south part of the valley, in the vicinity of Test Holes HS-1 and H-4. The surface of these consolidated rocks seems to slope upward to the east and to the north as indicated by gravity profiles, so that the depth to bedrock near the east side of the valley is about 4,000 feet and near the center of the valley along U. S. Highway 50 about 5,500 feet. Geophysical studies have not been made farther north in the valley but geomorphic interpretation would suggest that the bedrock is shallower in that direction.

Detailed information on the alluvial fill is limited to local areas around Frenchman and Test Holes HS-1 and H-4, where wells have been drilled. Driller's logs are available at Frenchman for wells that have penetrated 288 feet into the valley fill. These logs confirm data collected from Test Holes HS-1 and H-4 about six miles south. The drill log of a former well beneath the playa deposits of Labou Flat in the Bernard Navy Bombing Range south of Frenchman, reports essentially all "clay" (silt or silty clay?) to a depth of 400 feet. The logs of Test Holes HS-1 and H-4 provide the best available information on the alluvial fill to a depth of 935 feet (see Appendices C and F). These logs show that the alluvial fill is of very uniform lithology, consisting primarily of fine- to coarse-grained sand with some silt and very little clay. Only one layer of clayey material, with medium to high plasticity and a thickness of about 32 to 35 feet, occurs between depths of 530 and 565 feet. Even this layer contains only a little clay, and consists predominantly of silt and fine-grained sand. This layer serves as an aquitard between the two aquifers differentiated in valley fill in the drill hole vicinity. The mineralogical composition of the materials described in these two logs is characteristic of weathered granite and contains primarily sand and silt-sized particles of quartz and feldspar, with small amounts of accessory minerals including hornblende, magnetite, and zircon.







HIGHEST SHORELINE OF LAKE LAHONTAN 4380 foot elevation

FAULT Decined where approximately located

CONTACT Dashed where approximately located

WELLS

Our SPRINGS

GRANITE OF THE SAND SPRINGS RANGE

C

The valley fill is the result of deposition from streams carrying erosion products from the adjacent mountains. Because the streams flowed mainly in an easterly or westerly direction, and because many interstream areas occur with much finer sediments, it is almost impossible to correlate well logs in a north and south direction. Since these lens-shaped and finger-like strata change texture rapidly in both horizontal and vertical directions, correlation for long distances in any direction is difficult if not impossible. The latest deposition of these lenses and interfingering layers composing the alluvial fans makes up the present surface deposits in the valley and confirms this conclusion.

Four types of sedimentary deposits are found in the valley today; stream alluvium, alluvial fans, playa, and lake deposits. Most of the sediments have a common origin; they result from erosion and stream transport from the mountain ranges. In the southern end of the valley at elevations of about 4,300 feet, alluvial fans extend halfway across the valley. Large granice blocks four or five feet in diameter are found in the stream channels. When the streams flood, the roads may be covered in a few hours' time and several feet of sand, gravel, and boulders may be deposited. On the west side the fans are less dissected than those on the east side, and on Fairview Peak the streams are downcutting rapidly. At the northern end of Fairview Valley a large fan built out from the Stillwater Range extends almost across the valley. It is now modified on the east end by a small stream called Dixie Wash.

Several beaches of gravel and sand may be found on the east slope of the Sand Springs Range about seven miles south of Frenchman at an elevation of about 4,230 feet. Terraces and playa flats also occur near the 4,150 foot level. This is evidence that at one time a lake or lakes covered many square miles of the valley and might have been about 75 feet deep. The ages of these lakes are not presently known, nor is it known whether they were extensions of a lake in Dixie Valley. The sediments of these features are very fine and contain much clay due to the settling and reworking action of the lake waters. As mentioned above, 400 feet of clay was encountered by the well in the playa known as Labou Flat. About six miles north of this area several terraces mark the northern boundary of the lake in Fairview Valley. The lake deposits differ markedly in composition from the alluvial sediments, as the former are very fine sand, silt, or clay while the latter consist of coarse gravels, stones, boulders, or very coarse sand. On Figure 11 the alluvial fan and lake deposits are mapped as a single unit (Quf). The playa deposits are mapped as a separate unit (Qp), as are the recent alluvial deposits, primarily stream alluvium (Qr).

Fourmile and Eightmile Flats

The thickness of the alluvial fill in Fourmile and Eightmile Flats is probably much less than that in Fairview Valley. In Test Hole H-3 granitic bedrock was encountered at a depth of 310 feet. About 1½ miles downslope (northwesterly), at Test Hole H-2, bedrock was not encountered at a depth of 780 feet, the total depth of the well. Gravity measurements given in the geophysical report suggest depths of at least 1,950 feet in the valley.

Fourmile and Eightmile Flats are a reentrant of the large basin of the Fallon agricultural area. The sediments and soils of this reentrant furnish a detailed history of late Quaternary sedimentation, erosion, soil development, and climatic change, as well as a history of fluctuation of Lake Lahontan. This lake was a result of pluvial conditions existing during the Tahoe-Tioga periods of glaciation and was actually the result of a series of lake rises and declines (Morrison, 1961b). Glacial advances were approximately synchronous with rises in lake levels. Most of the drainage into Lake Lahontan was from the Sierra Nevada.

The Quaternary history of the basin around Fallon (exclusive of Fourmile Flat) was extensively interpreted and recorded in an attempt to set up geochronologic type sections representative of Late Quaternary time in the northern part of the Great Basin (Morrison, 1961a). The Quaternary sediments are differentiated into three main stratigraphic units by Morrison on the basis of lithologic differences and soil horizons (see Figure 12):

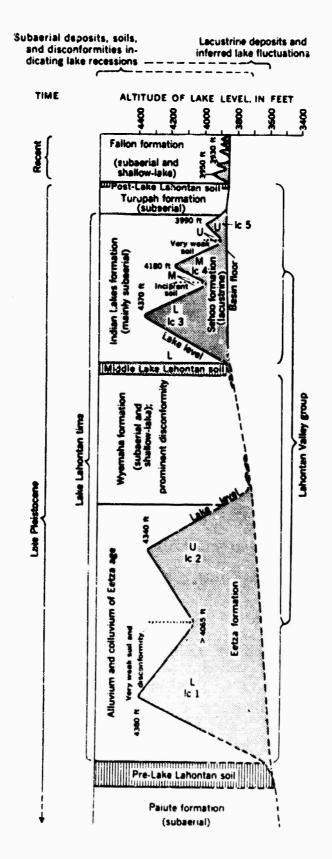
- 1. The Paiute Formation, a subaerial alluvial and colluvial sequence of later Pleistocene age that overlies Quaternary and Tertiary volcanics;
- 2. The Lahontan Valley Group, a sequence of intertonguing deep-lake, subaerial, and shallow-lake sediments of Lake Lahontan and post-Lake Lahontan time and;
- 3. The Fallon Formation, a succession of intertonguing subaerial and shallow-lake deposits.

Within the Lahontan Valley Group, Morrison's main distinctions between deposits depend upon the differences between subserial and lake sediment relationships as well as the presence of various soils which are effectively used as marker horizons.

Shorelines evident in the Carson Desert area are not by themselves good criteria for establishing the chronology of the Pleistocene lakes. Deposits must be identified and superposition of these deposits traced. Soils are an excellent criterion to use in this area in establishing a relative chronology.

Although the 869 square miles mapped by Morrison does not include the valley-fill deposits of Fourmile Flat, but terminates at the eastern edge of Eightmile Flat, the stratigraphic record depicted in Figure 12 is believed to be applicable to the valley-fill deposits in Four aile Flat. Field work accomplished in the present investigation substantiates the presence of readily recognizable Lahontan Valley Group (Late Pleistocene) and Recent deposits, distinguished by gross lithologic differences and the presence of soil horizons, which were the basis of Morrison's correlations.

Because of the nature of this project, it was decided that the mapping of valley-fill deposits in Fourmile Flat in the detail of Morrison was not as important as creating a geologic map based on gross lithologic differentiations of these deposits (see Figure 11).



Igure 12. Stratizraphic section of alluvial fill deposits (after Morrison, 1961a)

The criteria used in establishing the mapping units were gross lithology and applicability to the hydrologic problems. Therefore, most of the presently established units are known to be time transgressive. An example of this is the Quaternary sand dune (Qsd) deposits mapped as a gross lithologic unit of eolian sand (predominantly fine- to medium-grained). This sand is of Turupah and Fallon age (see Figure 12), although a portion of these eolian sands (those sand dunes mapped south of Well No. 1) may even be Wyemaha age.

Bedrock symbols are those used by the Nevada Bureau of Mines personnel and are modified only to the extent of placing an "M" before the rock type abbreviation.

Lahontan bar deposits (Q1b) and Lahontan lacustrine deposits (Q1) are believed to be correlative to the intertonguing Sehoo-Indian Lakes Formations. The Indian Lakes Formation is a subaerial coarse alluvium and colluvium while the Sehoo Formation is lake sediment of predominantly finegrained sand, silt, and clay composition.

Undifferentiated Lahontan Valley Group deposits (Qlu) are believed to be the age of sediments of the Lahontan Valley Group, with possibly some Recent alluvium.

The Recent lacustrine deposits (Qrl) mapped in Fourmile Flat are probably correlative in part to the Fallon Formation, a shallow-lake deposit (see Figure 12).

The high shoreline of Lake Lahontan, at the 4,380 foot elevation, is used to separate known Lahontan Valley Group sediments from the deposits described as undifferentiated fans. The ease of recognition of this shoreline both in the field and from aerial photos conveys the excellent preservation of the Quaternary geologic history of the area.

Sediments encountered in Telt Holes H-2 and H-3 consist primarily of fairly uniform sand, fine sand, and silt deposited by Lake Lahontan, and of eolian sands of late Pleistocene-Recent time. Interbedded with these deposits are alluvial fan materials, some of which are very coarse (one stratum encountered at 80 feet in Test Hole H-3 is made up of boulders of large dimensions). The surface and subsurface geology cannot be accurately correlated without detailed work. Ostracods believed to be correlative to ostracod faunas in Wyemaha or Sehoo deposits to the west, are present in samples taken from various levels of Test Hole H-2.

The alluvial fill in Fourmile and Eightmile Flats has been mapped in greater detail than that in Fairview Valley and South of the Cocoon Mountains because of the greater variety of sediments and other features available for outcrop study.

HYDROLOGIC CHANGES INDUCED BY EARTHQUAKES

Earth displacements known to have occurred in seismically active areas have been known to result in considerable hydrologic changes. For example, many authors report changes in discharge of springs and flowing wells as well as fluctuations in water levels. One of these reports (Zones, 1957) refers specifically to the region contiguous to the Sand Springs Range. In this paper he discusses water-level fluctuations on the order of four to eleven feet and discharge changes in the epicentral area where the intensity of the 1954 earthquake was VII based on the Modified Mercalli scale of 1931. Zones points out (1957, pp. 387-396) that such phenomena result primarily from tilting of aquifers, compaction of sediments over large areas, fracturing of rocks, and movement along faults. Further, in all instances he suggests that either increased or decreased water level or discharge would be temporary, and that eventually the balance between ground-water recharge, discharge, and storage would be reestablished with essentially no residual effect on the overall hydrologic picture.

It is doubtful that detonation of a device such as is proposed for Project Shoal would result in effects of even a sizeable fraction of those produced by the earthquake of 1954. Water-level changes within a mile or so of the detonation point probably will be undiscernible.

OCCURRENCE OF GROUND WATER

The occurrence of ground water in the consolidated rocks has already been described in general. Occurrence in the alluvial fill is discussed in the following paragraphs. Knowledge of occurrence of ground water in the alluvial fill is based primarily upon the results of the test-drilling program and upon scanty records of previous drilling operations in the valleys.

Results of test drilling in Fairview Valley indicate the presence of two aquifers separated by an aquitard in the upper 935 feet of valley fill at Test Holes HS-1 and H-4. The upper aquifer, 218 feet thick, is composed of fine- to coarse-grained sand with some silt, and layers or lenses of highly silty beds. Below the aquitard, which is 32 to 35 feet thick, the lower aquifer was penetrated about 120 feet and consists of somewhat finer-grained sediments than those in the upper aquifer. About five feet of clayey material, lithologically comparable to the aquitard between 530 and 565 feet, was penetrated at the base of the lower aquifer. The beds below this level may form a third aquifer. They were not tested for hydraulic properties. However, it appears to be a geohydrologic unit comparable to the other two aquifers. Between a depth of 813 feet and the bottom of Test Hole H-4 better stratified and consolidated, finer-grained sediments with many beds cemented with calcareous and siliceous materials were encountered. These strata are questionably assigned a Tertiary age.

Thus, at the Test Hole site water occurs in at least three aquifers separated by two relatively distinct aquitards. Under natural conditions, these units act as a single hydraulic system. The horizontal extent of this aquifer system is unknown and may be limited because of lateral and vertical changes in lithology.

Shallow aquifers were also encountered in Well Nos. 16, 17, 18, 19, and 24. These wells range in depth from about 280 to 350 feet. The log of Well No. 18 is given below. This well log is representative of sediments in the vicinity of Frenchman.

From Feet	To Feet	Thi ckness Feet	Type of Material
0	30	30	Silt and sand
30	42	12	Clay
42	55	, 13	Sand and gravel
55	144	89	Sand and grave
144	148	4	Coarse gravel
148	170	22	White clay
170	223	53	Sandstone
223	283	60	Sand and silt with thin gravel layers - water encountered at 227 feet.
283	288	5	White clay

On the west side of the Sand Springs Range, water was encountered in Test Hole H-3 in granite at a depth of 361 feet and the thickness of waterbearing granite penetrated was 119 feet. Down slope 6,000 feet from Hole H-3, in Hole H-2, water was encountered in a fine- to medium-grained, clean sand aquifer at a depth of 128 feet below land surface. This aquifer, 652 feet thick in Hole H-2, becomes coarser grained toward the bottom. Ground water occurs in predominantly finer-grained sediments than on the eastern side of the Range. These are lake sediments and occur up to approximately 4,380 feet above sea level, where often coarser alluvium underlies them. The alluvial and lacustrine sediments slope toward Fourmile Flat, except from the northwest. Thus, the Fourmile Flat playa is the major discharge area for both ground and surface water. From hydraulic gradients determined between Hole H-3, Hole H-2, and the playa, it appears that water occurring in the bedrock and in the alluvium is in direct hydraulic communication, established over a long period of time during which recharge and discharge rates were in approximate equilibrium.

Geonydrology

HYDRAULIC PROPERTIES

The hydraulic properties of the aquifers are determined primarily by pumping test analyses. The properties of greatest concern are the transmissivity and storage capacity of the aquifer. Values for these entities are most commonly expressed by the coefficient of transmissibility and the

coefficient of storage that appear in the Theis non-equilibrium formula and recovery corollary (1935), and in Jacob's modified non-equilibrium formula (1950).

The Theis equation is:

$$s = \frac{114.6q}{T} \qquad \frac{e^{-u} du}{1.87rS}$$
Tt

Where s = drawdown in feet at any point of observation in the vicinity of a well discharging at a constant rate.

q = discharge in gallons a minute

T = coefficient of transmissibility in gallons a day per foc:

 $S = coefficient of \epsilon$ prage

r = distance in feet from the pumped well to the observation well

t = time in days since pumping started

e = natural logarithm base

u = a dimensional variable between the given limits of integration

"The exponential integral is usually expressed as the well function of u or "W (u)".

The recovery method of determining the coefficient of transmissibility involves the use of the formula:

$$T = \frac{264q}{s'} \log_{10} \frac{t}{t'}$$

Where q and T are defined above

s = residual drawdown in feet at any instant

t - time in minutes since pumping started

t = time in minutes since pumping stopped

The value tover one log cycle of time reduces the logarithm to unity and s (the change in residual drawdown for one log cycle of time) may then be determined graphically over one log cycle. Thus, over one log cycle

$$T = \frac{264q}{\Delta s'}$$

A convenient way to express the transmissivity of the aquifer as by determination of the apparent permeability, P_a. The apparent permeability may be determined when the coefficient of transmissibility and the thickness of the beds, m, is known. Thus,

$$P_a = \frac{T}{m}$$

The values for apparent permeability as determined from the pumping tests are given in Table 4.

These formulas are readily adaptable to pumping test procedures that involve field measurement of values of discharge and drawdown for a known time. Several such pumping tests were run in Fairview Valley and Fourmile Flat and are described below in detail.

PUMPING TESTS IN FAIRVIEW VALLEY

On March 10, 1962, Test Hole HS-1 was pumped for 20 hours withdrawing water from the interval between 310 feet to 530 feet, and Test Hole H-4 was used for recording observations. Recovery observations were taken for 27 hours after pumping ceased. All measurements in the observation hole were taken with a Leupold-Stevens automatic water-level recorder calibrated by steel tape measurements at frequent intervals. Measurements in the pumping well were made by an air line with an attached water-pressure gage.

The total drawdown in HS-1 at a pumping rate of 66 gpm was 37 feet, thus the specific capacity is about 1.8 gallons a minute per foot of drawdown. The pumping test data curve is shown in Figure 13. A summary of the results is given in Table 4.

On May 5, the lower aquifer system (570 feet to 685 feet) at this site was tested using Test Hole H-4 as a pumping well and recording observations in Test Hole HS-1. This operation called for a reduction in casing size and utilization of the natural seal provided by the clayey layer at about 530 feet. That this seal was effective was demonstrated by pumping the lower aquifer system at Test Hole H-4 for seven hours with no measurable drawdown in the upper aquifer system at Test Hole HS-1. Measurements were taken in the annular space between the casings. These preliminary tests were made while Test Hole HS-1 was being deepened to 699 feet. However, when the 8 5/8-inch casing was emplaced at 685 feet, the seal between the casing and the clayey layer was broken. As a result, leakage occurred during the pumping test in Test Hole HS-1.

A semi-logarithmic plot of drawdown in Test Hole HS-1 against time indicated that movement of water to the lower aquifer from the upper aquifer occurred 10 minutes after pumping started. By extending the 10 minute section of the time-drawdown curve tack to the line of zero drawdown, it was possible to obtain a time value at the intercept. An approximation of the coefficient of storage was then obtained by application of Jacob's formula: S = 0.3 Tt /r², where T is equal to the coefficient of transmissibility of the lower aquifer system as determined from Test Hole H-4 recovery data (Figure 14), t is the time value at the intercept for the 10-minute portion of the time-drawdown curve (2.4), and r is the distance

TABLE 4. SUMMARY OF TRANSMISSIBILITY, APPARENT PERMEABILITY, AND STORAGE COEFFICIENTS DETERMINED BY PUMPING TESTS

WELL AND AQUIFER*	SPECIFIC	PUMPING TEST METHOD	COEFFICIENT OF TRANSMISSIBILITY (T)	COEFFICIENT OF STORAGE (S)	EFFECTIVE	APPARENT PERMEABILITY
H-4, HS-1 Upper Aquifer	1.8	Drawdown	17,100 gpd/ft.	2.04 X 10 ⁻⁴	219 ft.	78 gpd/ft ²
H-4, HS-1 Lower Aquifer	2.4	Recovery	11,000 gpd/ft.	2.45 X 10" ⁴	120 ft.	91 gpd/ft
Frenchman's Station Eight and Six Inch Diameter Wells	1.1	Drawdown	5,275 gpd/ft.	3.53 X 10 ⁻⁴	88.5 ft.	60 gpd/ft ²
H-3 Bedrock (Granite) Aquifer	a	00 to 00 to 00 to 00 to	≯200 gp3/ft.		2 2 2	
H-2, Fourmile Flat	20.0	Recovery	76,000 gpd/ft.		640 ft.	118 gpà/rt ²

*Pumped well is underscored

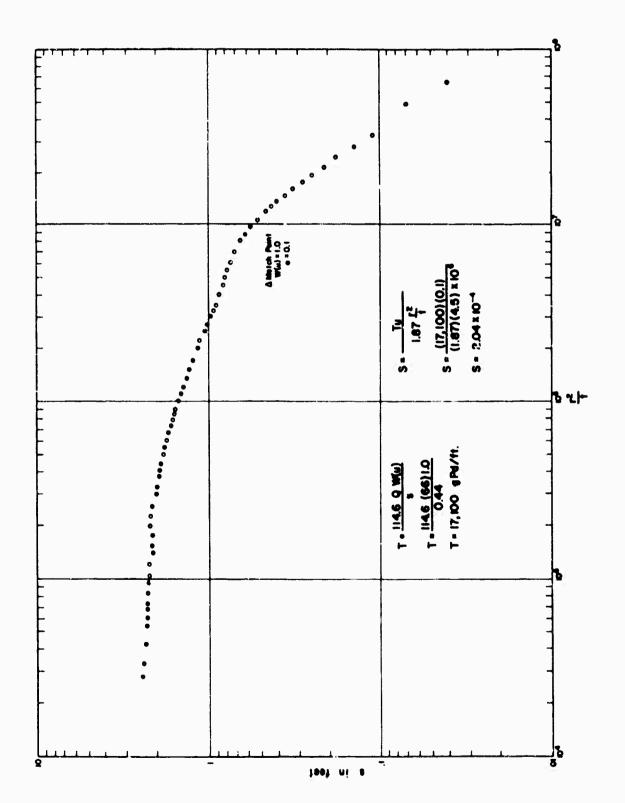


Figure 13. Pumping test data curve for the upper aquifor in Fairview Valley.

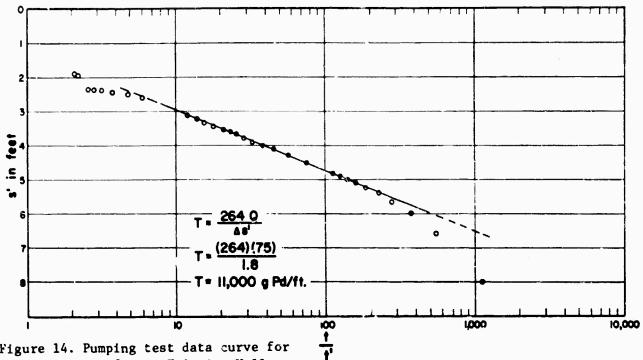


Figure 14. Pumping test data curve for the lower aquifer in Fairview Valley.

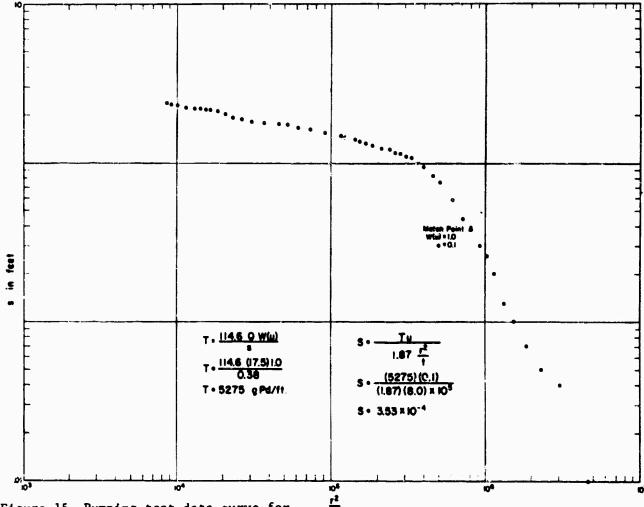


Figure 15. Pumping test data curve for Well 17 in Fairview Valley.

between HS-1 and H-4 (150 feet). A summary of the results is given in Table 4.

On March 15, an 18-hour pumping test was conducted at the domestic wells at Frenchman in Fairview Valley. The wells are owned by Mr. Edward Weyher. Mr. Weyher's eight-inch diameter well (288 feet deep) was pumped and drawdown was measured in a six-inch diameter well 80 feet away. The total drawdown in the eight-inch diameter well at a pumping rate of 17.5 gpm was 20 feet, thus the specific capacity is 1.1 gallons a minute per foot of drawdown. The pumping test data curve is shown in Figure 15. A summary of the results is given in Table 4.

PUMPING TESTS IN FOURMILE FLAT

On April 25, a pumping test was conducted or the granitic aquifer penetrated by Test Hole H-3. The primary interest in this test was to determine the approximate characteristics of the aquifer and, therefore, to establish a basis for determining the necessity of an additional test hole in the vicinity. The aquifer penetrated failed to respond satisfactorily to pumping test analysis. In less than one hour (55 minutes), at a low pumping rate of 33 gpm, 125 feet of drawdown was observed. The pump broke suction at this level. Further, eight feet of residual drawdown remained four hours after pumping stopped. Although water-bearing, the bedrock at this location has a very low coefficient of transmissibility, probably less than 200 gallons a day per foot.

On May 28, Test Hole H-2 was pump-tested. During the first few hours of the test, the well pumped a large amount of fine sand. The well improved during the test, but the data collected were practically useless. A second test was attempted on June 1, the data obtained being considerably better but still not satisfactory. This was primarily due to the difficulty involved in accurately measuring the small increment of recovery and drawdown in the pumped well. Inasmuch as the data do not indicate a straightline relationship between s and log t (see Figure 16), the coefficient of transmissibility reported is considered an approximation.

HYDROLOGIC TESTS AT PROPOSED GROUND-ZERO

Hydrologic tests were conducted between July 13 and 21, and August 1 to 4, 1962, on Core Hole ECH-D (elevation 5,233 feet) at the Shoal Test Site. Included in the discussion of these tests are detailed geologic and operational data which are necessary to discuss properly the hydrologic situation near Ground-Zero. In regard to both technical and safety aspects of the Shoal Project, the following three questions pertaining to the occurrence of water in the granite appear to be of most significance:

1. What is the elevation of the natural zone of saturation and the condition of saturation at Ground-Zero?

The water level, as determined during and after several tests ending on July 21, 1962 (see Figure 17 and Plate 8), consistently returned to an elevation of approximately 4,265 feet (approximately 968 feet from ground surface). Further tests conducted with a packer indicated that water was entering the hole at horizons above 4,061 feet (1,172 feet) in small quantities, and that it entered the hole in larger

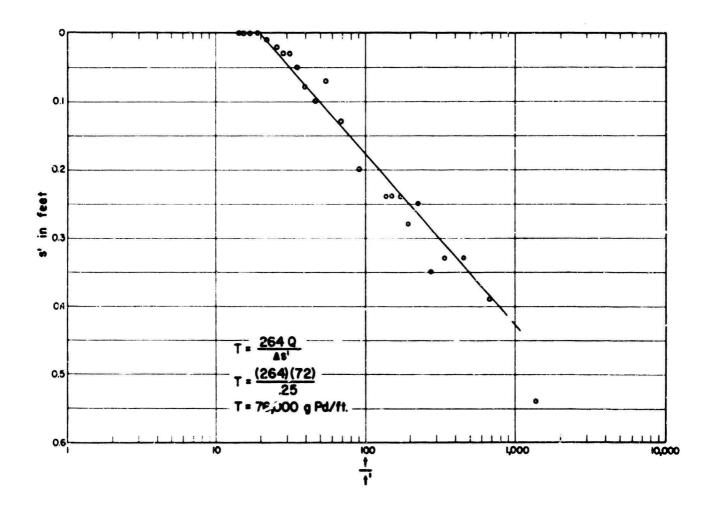


Figure 16. Pumping test data curve for Test Hole H-2 in Fourmile Flat.

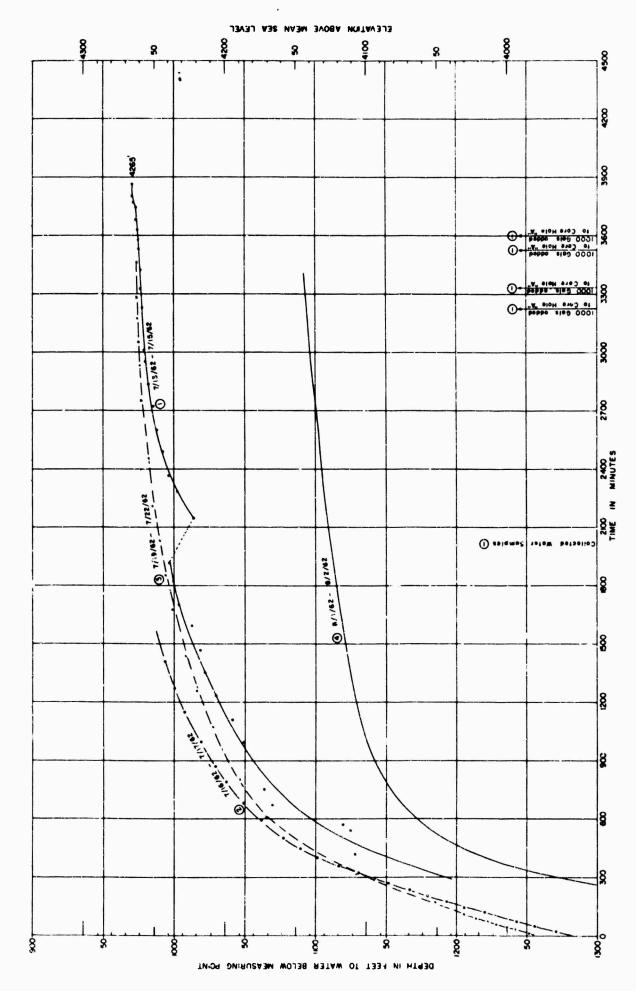


Figure 17. Recovery curves for Core Hole ECH-D

quantities below an elevation of 4,014 feet (1,219 feet). It is estimated that perhaps 80 to 90 percent of the water entering the hole came in between 4,014 feet (1,219 feet) and the bottom of the hole at an elevation of 3,878 feet (1,355 feet), and that over half of the water entered below elevation 3,951 feet (1,282 feet). In other words, all fractures below elevation 4,265 feet (968 feet from ground surface) are saturated and yield water to some extent, but the fractures near the bottom of the hole as of July 21 (elevation 3,878) transmit more water.

Plate 5 shows the position of joints, fracture cleavages, and faults. The average direction of jointing is N. 60° W., the same bearing as exists between the core holes; these joints are predominantly vertical. The fracture cleavage has an average trend of N. 30° E., and is either vertical or dips eastward at 70° to 90° .

Between the collars of the core holes, a linear distance of 1,376 feet, two major fault zones are mapped at the surface and these same fault zones are encountered at depth, as were many weaker faults.

The continuity of any given fracture or fracture system and hydraulic connection with other fractures is unknown and may be extensive or extremely limited.

During the period July 21 to August 1, Core Hole ECH-D was deepened an additional 220 feet to elevation 3,658, or 1,575 feet below ground surface. At elevation 3,794 (1,439 feet below ground surface), a fault was encountered dipping approximately 70° S., and probably striking east. The width of the fault zone is uncertain because the drill bit probably was deflected somewhat into the softer material in the faulted zone, but may be at least 75 feet.

On August 1, another recovery test was conducted, the results of which are shown in Figure 17. Although the recovery rate appears similar to the earlier tests, approximately 118 feet of head was lost, and the water level returned to elevation 4,147, or 1,086 feet below ground surface. An explanation for this is not readily forthcoming but may develop as study of the problem progresses. Meanwhile, the interpretation that only water introduced during drilling operations is involved is not necessarily supported by this loss of head.

2. To what extent had this level been affected by injection of drilling water during operations at ECH-A and ECH-D?

A total of 386,000 gallons of water were used in drilling ECH-A, of which an undetermined but relatively small fraction was recirculated to the surface. Circulation was lost almost consistently from the surface to approximately an elevation of 4,580 feet. The largest loss of circulation was at approximately an elevation of 4,950 feet, the position of a major shattered zone within the granite. Water that was not lost through this zone on the downward move may have been lost here with return circulation. Complete loss of circulation generally occurred as drilling proceede. through the major fault zones at about the 4,950 foot and 4,650 foot elevations.

Core Hole ECH-A was cased from the surface to an elevation of approximately 4,580 feet. The casing was later removed and a new casing inserted after the hole was drilled to an elevation of 4,140 feet. Below an approximate level of 4,580 feet circulation was never entirely lost, except for very small intervals, and even then the major loss may have been at the upper fault zones.

It is probable, then, that all voids within the fault zones are water-filled, and a combination of inclination of fault planes plus decrease in volume of void spaces below the fault zones, may serve as a more or less effective barrier to flow of water toward Core Hole ECH-D.

Because Core Holes ECH-A and ECH-D approach to within approximately 150 feet of each other, and considering the highly fractured granite, it is possible that some communication exists between the two drill holes. This is not to imply that a single, continuous system of fractures exists between the holes. During hydrologic testing of Core Hole ECH-D, 4,000 gallons of water were introduced into Core Hole ECH-A in an effort to letermine any communications between the holes. Nothing conclusive can be determined from the test.

During the drilling of Core Hole ECH-D 191,000 gallons of water were used, of which an undetermined amount was recirculated to the surface. It is highly probable that the use of air under high pressure during drilling operations forced some water into fractures in the granite walls of the hole. However, the heat and other characteristics of the drilling method assure that a large proportion of the introduced water returns to the surface.

Chemical analyses of water taken from three levels within Core Hole ECH-D (4,120 to 3,892 foot elevations) during hydrologic testing, plus a sample from the total section of water within Core Hole ECH-D as of July 14, were compared to analyses of the water injected into the hole. This comparison offers no evidence that water in ECH-D is largely introduced or indigenous. The closest similarities exist between ECH-D water and water from the deep aquifer of H-4. In general, the ECH-D samples show the following differences from Fairview Valley water: Slight increase in pH; increase in total dissolved solids, calcium, magnesium, sodium, sulfate, chloride, carbonate, bicarbonate, and alkalinity; and decrease in potassium, iron, and silicon. These differences may be only a reflection of the soap solution used in ECH-D vhile drilling.

On the basis of the data presented in answer to 1. above and the relatively small quantity of introduced water believed to be remaining in Core Hole ECH-D during the tests, it is concluded that naturally-occurring water must be present, and that the introduced water recharged the saturated zone to an unknown extent.

3. What problems might result from the occurrence of natural water in the granite?

It must be emphasized that quantitatively accurate data are not yet available on occurrence, movement, and storage of water in the granite. This primarily results from test-drilling methods used to date, from

lithologic conditions, and from depths at which observations were made. It is likely that drainage of water from the granite in the vicinity of Ground-Zero will be very slow, and completeness of drainage is unpredictable because the degree of fracturing and interconnection of fractures and faults is not predictable. Furthermore, because of geologic conditions such as lithologic and structural boundaries, it is not possible to accurately predict conditions of occurrence of ground water at even moderate distances (say 1,500 to 2,000 feet) from the core holes or from any other future test hole. Some additional data bearing on these problems will be forthcoming from logging operations and, possibly, from further hydrologic tests on Core Hole ECH-D, but it is unlikely that they will adequately enswer the questions herein discussed.

MOVEMENT

The ultimate source of all the water in this area is from local precitation and from influent seepage and surface flow from the Fallon area. In the Fourmile and Eightmile Flats most of the water is probably derived from the latter source, with only small contributions from precipitation on the low-lying surrounding mountains. In Fairview Valley south of U.S. Highway 50, essentially all of the ground water has originated as precipitation in the surrounding mountains and alluvial slopes. North of U.S. Highway 50 considerable, perhaps the major, contribution to ground-water recharge is made by Dixie Wash which drains a large area to the east. Some recharge is also supplied from the surrounding highlands. In both valleys, recharge from the Sand Springs Range is minimal, but some ground water does move toward the valleys through the alluvial and lacustrine sediments to points of discharge.

Fourmile Flat is a closed basin with a high water table. Essentially all discharge from the basin is accomplished by evapotranspiration. Fairview Valley ground water moves northward and discharges by underflow into Dixie Valley. Very small quantities of water are pumped for comestic and stock use and are eventually discharged by evapotranspiration.

In Pairview Valley the hydraulic gradient from Test Hole HS-1 northerly to Frenchman is about three feet per mile, and the gradient steepens considerably to 33 feet per mile from Well 24 to Well 25. The steepening over this reach is most likely a result of convergence of the valley walls (see Figure 10) and consequent reduction in cross-sectional area. The steep gradient, therefore, can be readily explained by Darcy's law. Vertical movement probably does not occur, especially since pumpage is slight and has produced no "low pressure" zones of any great extent.

Fourmile Flat functions as a point sink and, therefore, a point of convergence and natural discharge for ground water in the valley. It is quite likely that Eightmile Flat is an extension of the sink, although there appears to be a component of movement toward Fourmile Flat. For all practical purposes, that part of the basin extending from the alluvial fans on the west side of the Sand Springs Range to a point somewhere in the vicinity of the Fallon Naval Auxiliary Air Station can be considered closed, with radial flow toward the Fourmile Flat playa.

Little ground-water movement occurs toward Fourmile Flat through the alluvial and lacustrine mat tial flanking the Sand Springs Range. Assuming this flow direction, the hydraulic gradient determined from static levels. Test Holes H-3 and H-2 is almost flat, 0.56 foot per mile. This calcuion may be inaccurate, however, due to grease and oil left in Test Hole has a consequence of a pumping test and which caused difficulties in obtaining an exact static level. Perhaps the most accurate gradient determination can be obtained by utilizing the static level in Well 1 and Test Hole H-2. The hydraulic gradient measured from these points is 1.46 feet per mile. That the water is circulating slowly with very little freshening from meteoric-derived water is best illustrated by its chemical nature. This substantiates the concept of little or no recharge to the aquifer in this area.

The static level of Well 5 at Salt Wells is higher than the water level in Fourmile Flat and indicates that ground water is moving eastward toward the latter. However, movement of ground water in that general vicinity and farther west near the Fallon Naval Auxiliary Air Station is extremely complex, and direction of ground-water flow is influenced mainly by the low-level Carson Lake to the south, the Carson Sink to the north, and Fourmile Flat. These sinks are all approximately at the same elevation and receive water that is subsequently discharged by evapotranspiration. The surface and ground water encountered in the area east of Fallon and west of the Sand Springs Range may be regarded as one flow system with three or more sinks that control the boundaries of individual flow fields.

The rate of movement in Fairview Valley and Fourmile Flat varies from place to place, but is everywhere slow. This can be illustrated by computing the apparent rate of movement in those areas where the hydraulic properties are known with reasonable accuracy. Velocity of ground-water movement can be estimated by the following formula:

$$v = \frac{PI}{p}$$

where v equals the velocity of the ground water in feet per day, P equals the permeability in cubic feet a day per square foot, I equals the hydraulic gradient in decimal form, and p equals the porosity in decimal form.

The hydraulic gradient in the alluvial materials in Fairview Valley between Test Hole HS-1 and Frenchman is three feet per mile, or 0.00568. The permeability is 78 gallons a day per square foot, or 10.4 cubic feet a day per square foot. The porosity of the alluvium is not known, but probably ranges from 10 to 20 percent. From the above equation:

 $v = 10.4 \times 0.000568 = 0.059$ foot per day or 0.71 inch per day 0.10

If the porosity is estimated to be 20 percent, the approximate velocity of ground-water movement is 0.03 foot a day or 0.36 inch a day. If the permeability is estimated to be as the upper limit determined (95 gallons a day per square foot) and the porosity to be 10 percent, ground-water velocity is increased only slightly to 0.072 foot per day. It is concluded, therefore, that the low gradient is the significant control on the velocity of ground-water movement, and it is doubtful that average velocities exceed

25 feet a year. This would require over 1,000 years for water now in the vicinity of the test-hole site to move into the Frenchman area. The above figures are approximations and indicate only a general order of magnitude.

The hydraulic gradient in Fourmile Flat is at a maximum 1.46 feet per mile, or 0.000277. The permeability is estimated to be 118 gallons a day per square foot. The porosity is estimated to be between 10 and 25 percent. Then,

 $v = 15.8 \times 0.000277 = 0.044$ foot per day or 0.53 inch per day 0.10

If the porosity is estimated to be 25 percent, the velocity decreases to 0.0175 root per day, or 0.21 inch per day. As an approximation, the ground water then travels about 16 feet per year.

Little is known about vertical movement of water in the unsaturated zone, and essentially no data bearing on this matter have been collected in this investigation. Upward movement by capillary rise probably could not exceed approximately 40 feet, because essentially no fine-grained sediments (particles less than 10 microns in diameter) are known to exist in the valley fill. Downward movement resulting from gravity must occur because the aquife s are recharged from precipitation and surface flow.

In the saturated zone at the Test Hole site (HS-1 and H-4) in Fairview Valley, head differences in the various aquifers were not observed, although care was taken to detect such differences during drilling. Therefore, it is assumed that little or no vertical movement occurs between aquifers there.

In the Fourmile and Eightmile Flats flowing wells are known at widely separated points (see Well Nos. 2, 7, and 11, Figure 10). Water also stands at or near the surface in this area. Since the static level of water in these flowing wells must rise above the land surface and the water at lower head must be at or below the land surface, a hydraulic gradient occurs from the lower to the upper body of water. Since water moves from the points of high potential to lower potential, upward movement of water takes place.

The nature, direction, and rate of movement of ground water in the valley fill bears directly on the problem of probability of contamination from the Shoal experiment. As is demonstrated above, the lateral movement of ground water is very slow. In valley fill sediments in comparable areas the rate of vertical movement of water is usually a fraction of that of horizontal movement because of bedding and other sedimentary features of the rocks. Therefore, even in the unlikely event of contamination reaching the alluvial fill, the probability of contamination of present sources of ground water is very low.

Chemistry and Temperature of the Water

The chemical constituents of the water collected (through June, 1964) from all known water points in the study area are shown in the analyses in Appendix G. Illustrations of some of the constituents from these analyses are shown in Part II, Section B. Fig 11,12 Concentration of six ions, in

equivalents per million, are shown by a method modified from that of Stiff (1951) and Sinclair (1962). The chief modification is that of scale. Where a linear scale was previously used, an expanding scale to make diagramatically possible the illustration of a large range of concentrations is adopted.

On the figures in Section B the pattern of diagrams clearly illustrates compositional differences that retlect environmental, recharge, and time factors. In Fairview Valley the ground water contains little dissolved solids and is potable. The concentration of total dissolved solids increases down-gradient, as between Test Hole HS-1 and the wells at Frenchman (Well Nos. 17 and 18). This normally occurs in an area of active circulation of ground water. The greater amount of sodium in the Frenchman wells may be related to movement of water over grapitic terrain or through lake sediments, or both. Apparently the sodium increases in combination with bicarbonate, sulfate, and chloride.

Analyses of the water from Core Hole ECH-D are somewhat similar to that of a spring in the Sand Springs Range (No. 30 in Section 36, T. 15 N., R. 32 E.).

In Fourmile and Eighmile flats, analyses of water known to have passed through lake and playa sediments exhibit gross chemical differences from analyses of water from wells in Fairview Valley and wells predominantly in alluvial apron sediments in Fourmile Flat valley. The constituents in the water from the lake sediments are predominantly sodium and chloride. Sulfate and bicarbonate occur as major constituents, whereas calcium and magnesium usually occur in concentrations of a few equivalents per million. This water is, of course, unpotable and odoriferous.

The high concentrations of sodium, chloride, sulfate, and bicarbonate verify the conclusion that the water is stagnant or almost stagnant as shown by the hydraulic gradients in this area. Further, this water undoubtedly has been in contact with or passed through the salt and alkali beds, peat bogs, and other sediments characteristic of lacustrine lagoonal deposits.

In water from the wells in the fan deposits (Well Nos. 1 and 4) the lower concentration of sodium and chloride relative to concentrations of calcium and magnesium indicate that recharge reaches these areas. Water from the recharge area probably has flushed salts out of these sediments and, of course, the fresh recharge water dilutes the preexisting water in the aquifer.

The water from Test Hole H-3 high on the alluvial slope comes from granite. Its quality is more characteristic of the saline waters of the Flat than of the waters from Well Nos. 1 and 4, although it contains considerable calcium and magnesium. Possibly this denotes some recharge by fresh calcic waters and consequent dilution of the saline water.

Calcium and magnesium occur in diminishing concentrations down the fans and into the Flat where they are relatively inconspicuous. Perhaps this denotes base exchange whereby the calcium and magnesium ions become fixed in the clay mineral elements of the sediments.

Temperature logs were run by McCullough Tool Company on April 14, 1962 in Holes H-4 and H-3. In Hole H-4 the logged interval was from an 875 foot depth to the surface with a static water level occurring at 300 feet. The temperature gradient decreased from 69°F. at 875 feet to a low of 51.5° at 340 feet. The gradient then increased to 54° at 300 feet, and then to the air temperature of 94° at the surface.

In Hole H-3 the logged interval was from 480 feet to the surface with a static water level at 329 feet. The temperature gradient decreased from 58° F. at 480 feet to a low of 55° F. at approximately 400 feet, then increased to 58° at 329 feet, and then to 86° at the surface.

TABLE 5.

Temperatures (°F) of Water from Wells

Well No.	Temperature	Date <u>Sampled</u>	Well No.	Temperature	Date Sampled
1	60	3/23/62	16	64	5/16/62
3	66	3/24/62	18	60	5/22/62
6	60	4/10/62	19	59	5/22/62
7	70	4/13/62	20	61	5/ 2 5/ 6 2
9	64	4/16/62	21	60	5/26/62
10	60	4/16/62	HS-1	65	2/18/62
11	63	4/17/62	*H-4	50	4/23/62
12	64	4/17/62	32	55	6/ 6/62
		•	*Depth 320 fe	eet	

Probability and Extent of Contamination

Preliminary study of distribution coefficients of material determined in other areas (Higgins, 1959) such as the Nevada Test Site and Hanford, indicates that the granite in the Sand Springs Range and the alluvial fill in adjoining valleys would rapidly fix the radionuclides resulting from the proposed test shot. It is presently deemed safe to say that under ordinary conditions of underground movement of water at the estimated gradients in the Range, the radionuclides will not travel beyond the range front.

If these estimates and this conclusion are in error and radionuclides should be carried by ground water into the alluvial fill, they will be fixed within a short distance of the range front. This conclusion is substantiated by the following:

- 1. The gradients in the valley fill are very low, and the more or less uniform permeability of any section of the alluvial fill precludes anomalously rapid movement. Velocities calculated from the known gradients and permeabilities are low, on the order of three feet per mile in Fairview Valley and 1.46 feet per mile in Fourmile Flat.
- 2. The distribution coefficient of the alluvium is certainly higher than that of the granite, for the alluvium is the weathered product of the granite, and is composed of discrete particles with much

more exposed surface area.

The conclusions given above are based on the assumption that the shot will be wholly contained.

REFERENCES

- Army Map Service, 1:250,000 scale topographic map, Reno sheet.
- Birch, A., Schairer, J. F., and Spicer, H. C., 1942, Handbook of Physical Constants: Geol. Soc. America, Spec. Paper 36.
- Bott, M. H. P., and Smith, R. A., 1958, The estimation of the limiting depth of gravitating bodies: Geophys. Prospecting, v. 6, no. 1, pp. 1-10.
- Hardman, G., and Mason, H. G., 1949, Irrigated lands of Nevada: Nevada Univ. Agr. Sta. Bull. 183, 56 pp.
- Higgins, G. H., 1959, Evaluation of the ground-water contamination hazard from underground nuclear explosions: University of California, Ernest O. Lawrence Radiation Laboratory No. UCRL-5538 Revised, 23 pp.
- Holmes & Narver, Inc., May 1961, Reconnaissance survey of possible sites outside of California for Shoal Event, Project Shade: 21 pp.
- Jacob, C. E., 1950, Flow of ground water: Engineering Hydraulics, H. Rouse, ed., John Wiley and Sons, New York, pp. 321-386.
- Morrison, R. B., 1961a, Lake Lahontan stratigraphy and history in the Carson Desert (Fallon) Area, Nevada: U. S. Geol. Survey Prof. Paper 424-D, pp. D-111 D-114.
- ,1961b, Correlation of the deposits of Lakes Lahontan and Bonneville and the glacial sequences of the Sierra Nevada and Wasatch Mountains, California, Nevada and Utah: U. S. Geol. Survey Prof. Paper 424-D, pp. D-122 D-124.
- Sinclair, W. C., 1962, Ground-water resources of Desert Valley, Humboldt and Pershing Counties, Nevada: State of Nevada, Department of Conservation and Natural Resources, Ground-Water Resources Reconnaissance Series, Report 7, 23 pp.
- Stiff, H. S., 1951, The interpretation of chemical water analyses by means of patterns: Jour. Petroleum Technology, pp 15-17.
- Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., v. 16, pt. 2, pp. 519-524.
- Thompson, G. A., 1959, Gravity measurements between Hazen and Austin, Nevada: a study of basin-range structure: J. Geophys. Research, v. 64, no. 2, pp. 217-229.
- Twenhofel, W. S., Moore, J. E., and Black, R. A., July 1961, Preliminary evaluation of the seismicity, geology, and hydrology of the northern Sand Springs Range, Churchill County, Nevada, as a possible site for Project Shoal: U. S. Geol. Survey TEI-796, 20 pt.

- University of Nevada, 8 November 1961 (Proposal covering the exploration phase of work involved in determining the suitability of the Sand Springs site for the Shoal Event): 18 pp.
- N. B. M.
- July 1962 (periodic), Memorandum, current status of University of Nevada's exploratory program for Project Shoal, Sand Springs Range, Nevada.
- Nevada's exploratory program for Project Shoal, Sand Springs Range, Nevada: 16 pp.
- the hydrologic tests conducted since July 13, 1962 on ECH-D at the Shoal Test Site): 5 pp.
- Weather Bureau, U. S. Dept. of Agriculture, Climatic summary of the United States, climatic data herein from the establishment of stations to 1930, inclusive: pp. 19-11, 19-24, 19-25, 19-28, 19-29.
- Weather Bureau, U. S. Dept. of Commerce, 1962, Climatological Data, Nevada, Annual Summary 1961, v. 76, no. 13, pp. 150-151.
- Winkler, H. A., 1962, Simplified gravity terrain corrections: Geophys. Prospecting, v. 10, pp. 19-34.
- Zones, C. P., 1957, Changes in hydrologic conditions in the Dixie Valley and Fairview Valley areas, Nevada, after the earthquake of December 16, 1954: Seismol. Soc. America Bull., v. 47, no. 4, pp. 387-396.

APPENDIX A

Log of Diamond Drill Hole ECH-A

Location: N. 1,619,292.72-E. 558,740.32
(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Bearing: N. 60° W.

inclination: -45°

Collar elevation: 5,158.90 ft.

Date begun: February 28, 1962

Date completed: June 21, 1962

Drilling contractor: Sprague and Henwood

Logged by: NBM personnel: L. Beal, R. Horton, S. Jerome, I. Lutsey, H. Mossman, J. Schilling, and R. Wilson

Explanation: The orientation of fractures and faults shown in the log are given only in relation to the axis of the hole (which is parallel to the columns in the log), and not in-relation to each other; their strikes and dips cannot be determined.

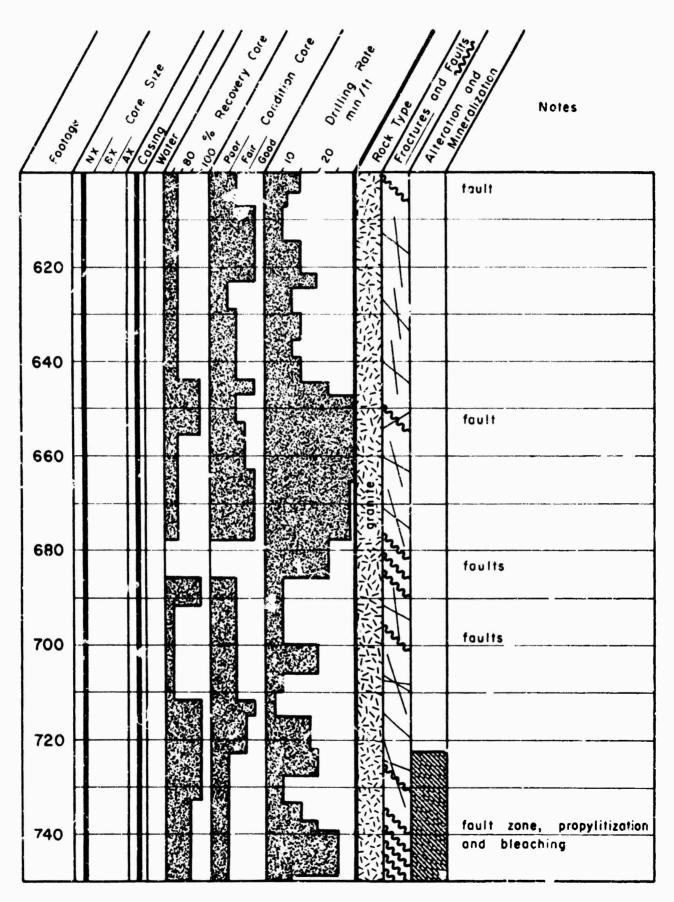
Core in cylindrical pieces is considered as in "good" condition, core in large angular pieces as in "fair" condition, and more finely broken-up (c-umbled) core as "poor."

, co, co, co, co, co, co, co, co, co, co	\$\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	\$\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	Notes
20			soil and decomposed granite
40			
60			
80			weathering
100		granite	
120			
140			faults

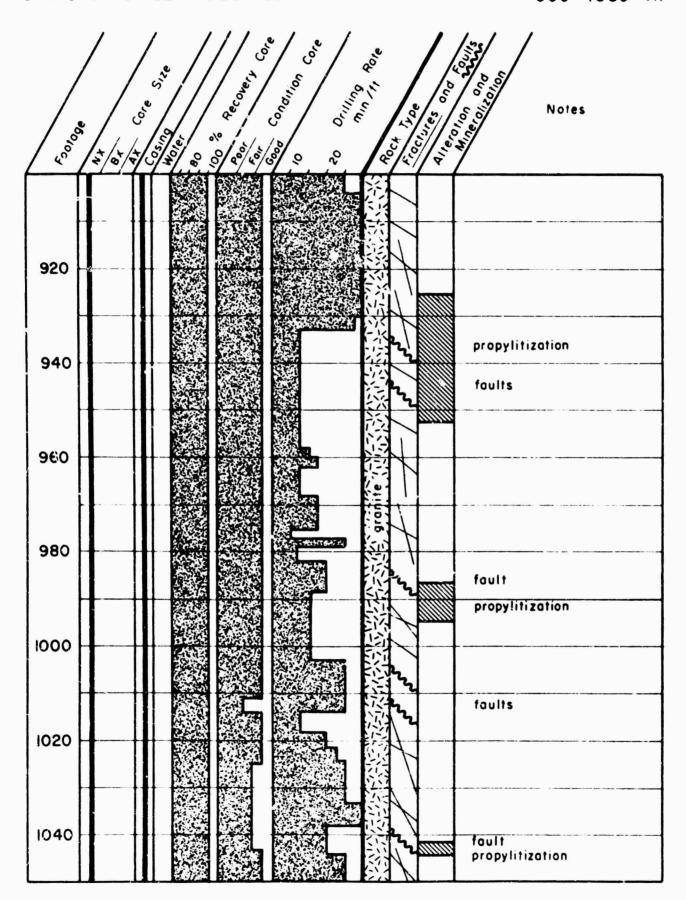
0000 go	/ &		100 1 10 10 10 10 10 10 10 10 10 10 10 1	Note:
160			Serve L	fault
180				fault zone and
200				bleaching
220			gron le	foult
240				faults
260			10000000000000000000000000000000000000	faults and propylitization
280				fault zone and
				bleaching

0,000	/ 3	194.1	Secondary Second	Conemon	10 1 10 6 10 6 10 6 10 6 10 6 10 6 10 6	Notes
					(X) 2-2 (X) 2-2 (X) 2-2	faults
\$20					N. S. P.	
		2000		ज्यतक -	11 00 11 00 12 00 12 00	faults
340						
360					1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	faults, propylitization and bleaching
		200				one biodening
380					igro)	
400						well developed fracture cleavage
420						
420						
440			Ş			fault zane and bleaching
440				100 700-0	營人	

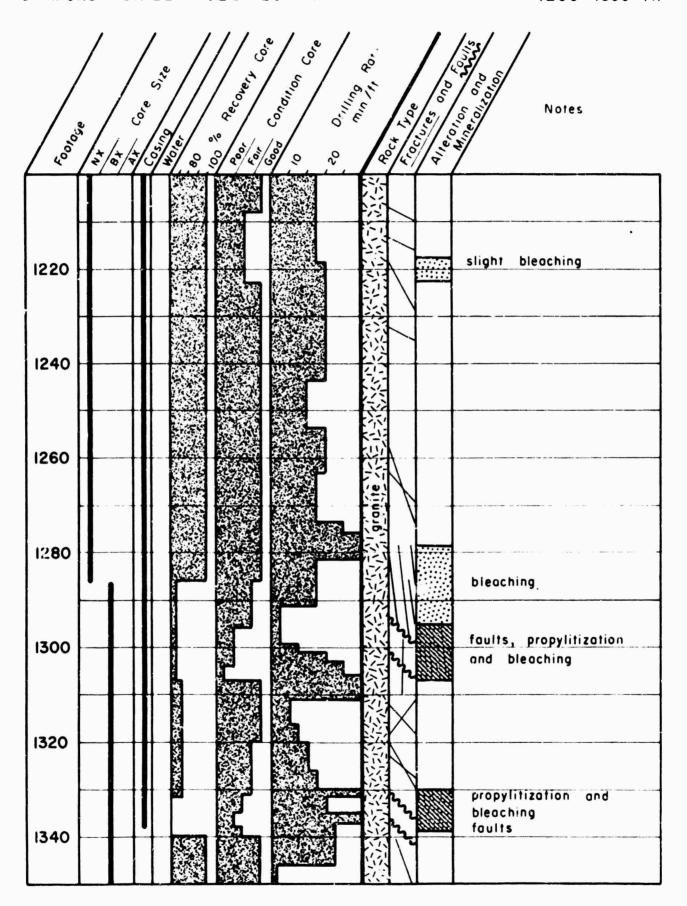
, co, co, co	/ 3		Notes
48	*\\$\\$\\\	3/3/ 2 3/3/4	
460			
480			
500			
520			John John John John John John John John
			56
540			
560			
580			



	/ 5	Secondary Contraction of the con	on 100 00 00 00 00 00 00 00 00 00 00 00 00	100 100	Notes
100 NO.	z z z z s				
760					
				and	zone, propylitization bleaching
780					
				P. V	
800					
			Services Services		
820				fault	
840	1				
				2	
860				faults	propylitization bleaching
					•
880					



, co, co, co, co, co, co, co, co, co, co	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	\$ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\	Cononion O	10 11 00 PO	1 (1 (1 (1 (1 (1 (1 (1 (1 (1 (Notes	
1060				新教教			
1080				が次次が	1		
1100				沙沙公公			
1120				/ Stoning /		propylitization	
1140				※※※※	200	fault	
1160				· · · · · · · · · · · · · ·			
1180				沙沙沙沙			
					72	g fault and bleached	



600,00°	/ (*/s		\$ 00 00 00 00 00 00 00 00 00 00 00 00 00	Conemon	10 1 1 10 de		41/ec/ 20/0/2/		Nates	
1360					大学の意思	27		fault ai	nd prapylitizat	ian
1380					次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次次	5/ 853/55		faults,	nd bleaching prapylitization	
1400					10000000000000000000000000000000000000	600				
1420					granite 7	1				
1440					表示法院					
1460					以	/				
1480					於公表別		V			

600,00°		2.5 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	200 % 00 % 00 % 00 % 00 % 00 % 00 % 00	600 Conanion Core	10 11 40 P	10 / 10 / 10 / 10 / 10 / 10 / 10 / 10 /	4/16/00 000 E		Notes	
						کی			opylitization aching	
1520					表於	1	isilisi:	and ble	aching	
					水淡					
1540			Ľ			ممم		fault		
					经					
1560						\				
					granife					
1580						1				
					※※	1				
1600					沙沙					
1620					総派				-	
.525					巡			ALC HIP MANAGEMENT		
1640					淡淡	\				
.040					総					

/	/	/			// G	Congrigor Core	100 11 00 W	/.	loug of		/	Notes
7000	\$ /x	/		5/5/ 0				201 201	\$ S S S S S S S S S			
1660							沙沙沙	Y				
			$\frac{1}{1}$				沒盆				·	
1680		-	$\frac{1}{1}$				公然					
		-	$\ \cdot\ $				· · · · · · · · · · · · · ·					
1700		+										
1720							onite!					
		-10- 0-1			Ţ		SXT gra	ممم	33734E6	fault	and	bleaching
1740	-		$\ \cdot\ $				沙沙沙					
			H				次次次				•	
1760							经济					
1780							公公					
			-				淡淡					
						PARENT VAN	恣。					

00,00	\$\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	8/8/2	(0) (0) (0) (0) (0) (0) (0) (0) (0) (0)	A S			Notes	
i820				※※※※※※				
1840								
1860				granite (NAVA)				
1880				1300%				
1900	-			2.5		-		

APPENDIX B

Log of Diamond Drill Hole ECH-D

Location: N. 1,619,975.66-E. 557,545.47

(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: Vertical

Collar elevation: 5,236 03 ft. (7.1 ft. above ground surface)

Date begun: May 26, 1962

Date completed: August 16, 1962

Drilling contractor: Core Drilling, Inc.

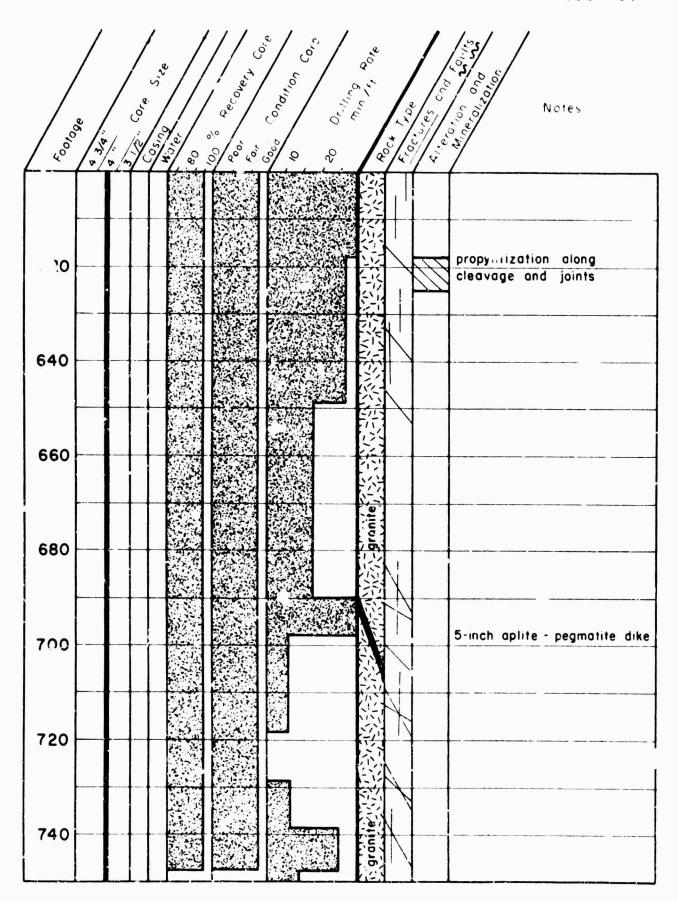
Logged by: NBM personnel: L. Agenbroad, R. Horton, S. Jerome, H. Mossman, and J. Schilling

Explanation: The orientations of fractures and faults shown in the log are given only in relation to the axis of the hole (which is parallel to the columns in the log), not in relation to each other. Their strikes thus cannot be determined, and fractures and faults which are shown as parallel in the log may have parallel strikes, and dip at the same angles but in the same or opposite direction; or may have different strikes, and dip at the same angle but in different directions.

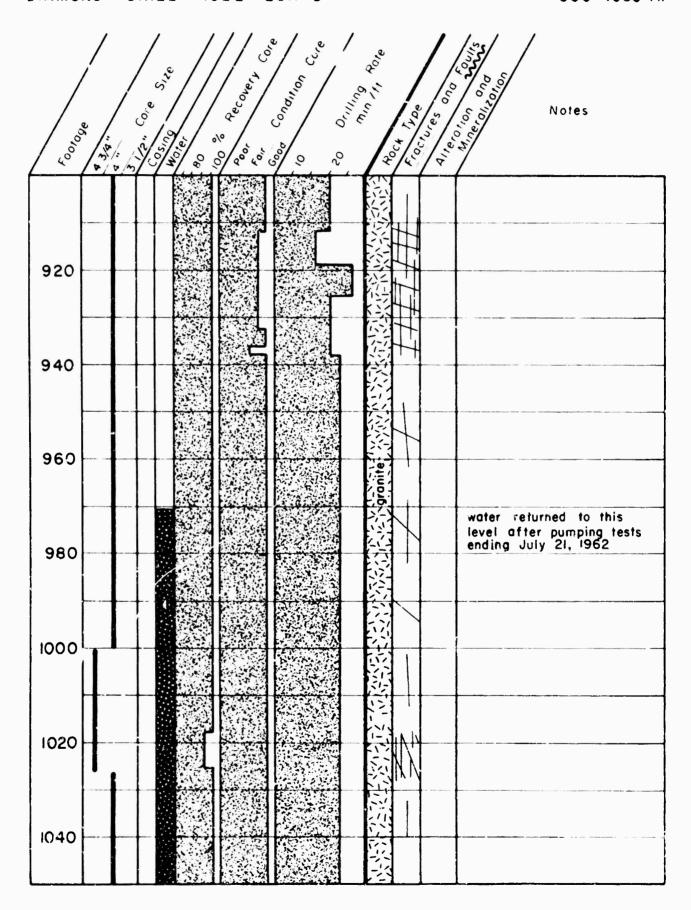
Core in cylindrical pieces was considered as in "good" condition, core in large angular pieces as "fair," and more finely broken-up (crumbled) core as "poor."

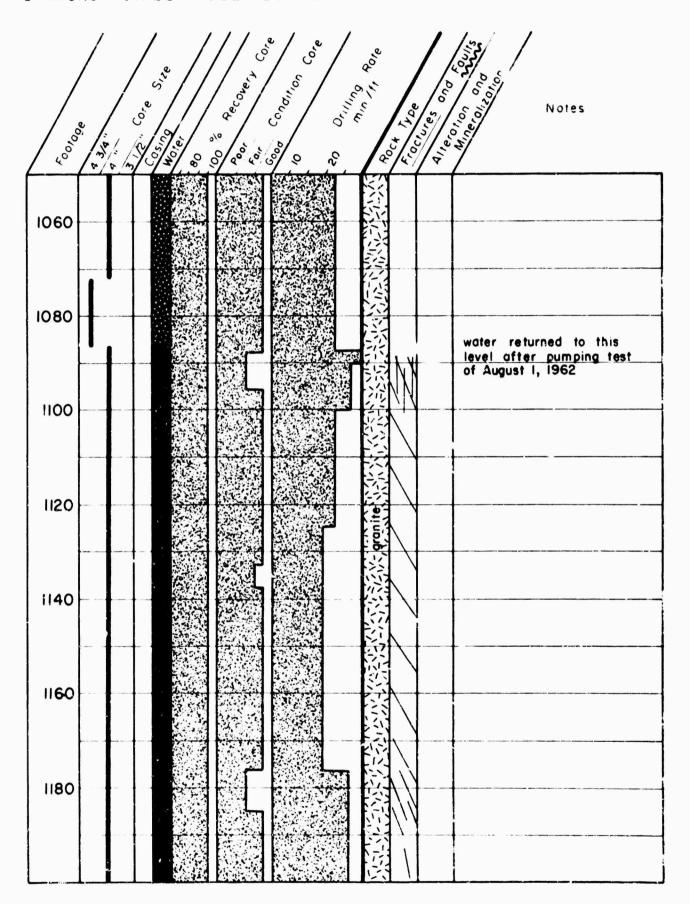
	13
4 / 0 / 0 / 0 / 0 / 0 / 0 / 0 / 0 / 0 /	hole was not cored above 307 ft. — cuttings show no evidence of alteration
320	evidence of discission
340	
360	
380	core lost by redrilling
	core lost by redrilling
400	
420	propylitization along cleavage and joints
440	core lost by redrilling

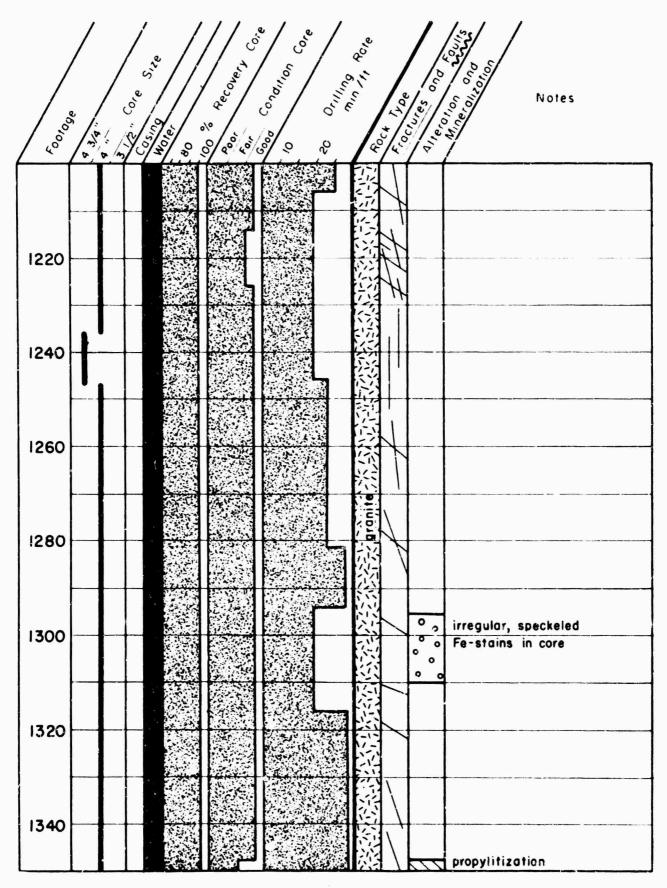
00000	\$ \\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	/ !-]:		///	Solver So	0,1100	10 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	4//es 9/0	Notes
	\ \psi \	~\^ 	73		1000			K/A	
460							滋		
100									propylitization along cleavage and joints
400							烈		
480									
							No.		
500							影		core lost by redrilling
							烈		
520							granite		propylitization along
									cleavage and joints
540									core lost by redrilling
							然		
560							國		well developed cleavage
580								7777	



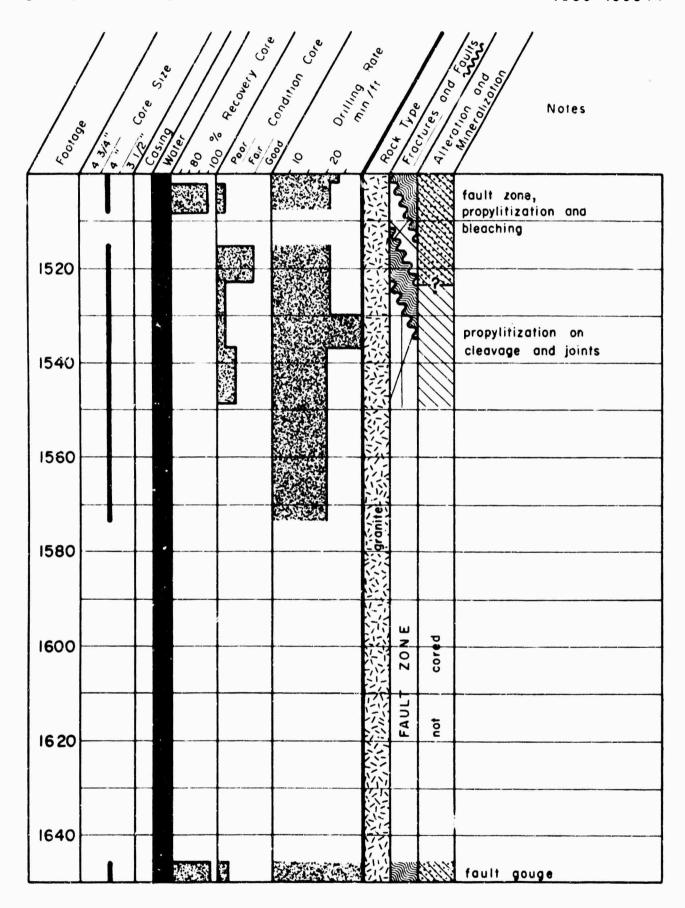
, coo, ou			1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	00,111,0	100 11 100 A	_/	1 Sold Sold		otes
760			\$45. \$45.		经外交	$\langle \rangle$		propylitization bleaching	and
780					老还在然	<u>/</u> \^			
800					のでは、	//			
820					granite (1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/	7		bleaching	
840					污淡水沙	1			
860					经公公公	7			
880					水水水水水	+ +			
					然必				







, co, co, co, co, co, co, co, co, co, co		1 8.5 S. 18 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	20 20 20 20 20 20 20 20 20 20 20 20 20 2	Conomo	104 11 4016		Alle Cond	Votes
1360					が実際	1		
1380					なの意思	4		
1400					经验公 公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公公	/		
1420	-				S. S. Jaranite			propylitization on cleavage and joints
1440	1				並然外外感			
1460			 6 March 1997		学 经验公公公			propylitization and bleaching
1480					北京学院			fault zone propylitization and
			N-49-31		水			bleaching



60,00			Lecoret Control of Con	Conomo on the co	104 11 m	/	41/6/6 Sud	Notes
1660					人工大学			
	* - T				不然然	2 2 2 2 2 3		irregularly shattered, bleached, and propylitized
1680					方法的	ح ر ا_		
1700								
1720					ite			bleaching and propylitization
					A Granite	/		along joints
1740					学兴兴兴			
1760						2		
1780					子公公的			fault and bleaching
					步步以	1		

\ \&\/	0,000 / 11.00	1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	Notes
		\\ \frac{\z}{\alpha}\ \z\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	z /
1820			bleaching and propylitization along joints
1840		3	fault and bleaching
1860			fault and bleaching
1880			fault and Eleaching
1900			bleaching along joints
1920		え	fault and bleaching
1940			bleaching along joints
		灣川蓝	

, o o o o o o o o o o o o o o o o o o o			100 17 VIII 12 12 12 12 12 12 12 12 12 12 12 12 12	100 / 100 /	Notes	
1960			公司公司			
1980			Samile			
2000			12.22		l inch aplite – pegmatite dike	
2020	1		**2	33333	fault and bleaching)

EXPLANATION FOR APPENDICES C, D, E, AND F

Hydrologic Test Holes

The procedure used in describing lithologies and water-bearing properties encountered in Hydrologie Test Holes HS-1, H-4, H-3, and H-2, Project Shoal, is as follows:

MAIN LITHOLOGY (preceded by qualifying adjective(s) if accessory lithologies are present as 15 percent or more of the total sample): eolor; texture characteristics (grain-size and shape), preceded by the percentage of that texture present in the total sample; percent of the total sample that is non-quartzose; accessory minerals; nature of the eementing material; fossils, if present; comments on genesis or other special remarks.

Clastic sediment textures were determined by comparison with particles of known size and shape standardized by the Wentworth scale, as summarized below:

Medium gravel greater than 4.0 mm
Fine gravel 2.0 mm - 4.0 mm
Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Silt less than 1/16 mm

Percentages of clay were estimated by the plasticity of the sample, and described as being slightly or moderately plastic, plastic, or very plastic. If a particular sample interval was determined to be either plastic or very plastic, it was termed a clavev interval.

Each well log will be preceded by a summary of the lithology and water-bearing properties.

To eonserve space on the accompanying logs, the following characteristics will apply to all sample intervals, unless otherwise specified:

- 1. Sands are subangular to subrounded, and are quarezose.
- 2. Gravels are fine to medium grained, subangular to subrounded, and are quartzose and felspathic.
- 3. Rock fragments are fresh, angular particles, probably broken by the drilling tool, and are fine to medium grained.
- 4. Samples are ealeareous or have some degree of caleareousness.
- 5. Color of the sample is light brown when dry, darker brown when wet.
- 6. The feldspathie portions of gravel in Test Holes HS-1 and H-4 are predominantly potassium feldspars, while in Test Holes H-3 and H-2, sodium and ealeium feldspars are predominant
- 7. In Test Hole H-2, the nonquartzose percentage of the sample interval consists of biotite mica. hornblende, olivine, zircon, fine-grained aeidic and basic igneous and metamorphic materials.

Very fine- to medium-grained sand (or very fine- to fine-grained)	
Medium- to coarse-grained sand (or medium- to very coarse-grained)	
Very fine- to very coarse-grained sand (or fine- to coarse-grained)	
Clay	
Silt	
Gravel and rock fragments	
Microfossils	• • • • • • • • • • • • • • • • • • •
Bedrock-	
weathered	
unweathered	

APPENDIX C

Lithologic Log of Test Hole HS-1, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: East flank of the Sand Springs Range, in Fairview Valley.

NEVADA STATE COORDINATES: N. 1,622,141.28; E. 576,875.65.

Ground ELEVATION: 4,243.76 feet above sea level.

TOTAL DEPTH: 600 feet below ground surface.

SAMPLEO INTERVALS: Cable-tool cuttings taken either every five fect or at a distinct change of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole HS-1 was drilled in Quaternary alluvium consisting predominantly of sands, with varying amounts of clay, silt, and gravel. The description of the alluvium is based on samples obtained by the cable-tool method of drilling, and consists of a binocular study of the total section. Procedure followed in describing the alluvial rock fragments is listed on page 98.

Confined ground water was encountered in sand at a depth of 312.0 feet below ground surface. Overlying the top of the sand aquifer are approximately 70.0 feet of fine-grained, silty sand. After drilling to a depth of 530.0 feet below ground surface a fine-grained, claysy, silty sand was encountered, approximately 32.0 feet thick. This interval serves as an aquitard between the upper and lower aquifers, the latter consisting predominantly of sand, with a higher percentage of clay and silt than the upper aquifer.

Surveys conducted by Holmes & Narver, Inc., after completion of HS-1 indicate a true depth of 699.0 feet, rather than the 690.0 feet reported by the driller.

Lithology and Woter-Beering Properties	
Sand: 85 per cent fine- to coarse-grained sand; 5 per silt; 10 per cent gravel; organic debris. Sand: 85 per cent fine- to very coarse-grained sand; per cent silt; 5 - 10 per cent gravel, becomes more mi toward the bottom.	5 - 10
Sand: 85 per cent very fine- to very coarse-grained a predominantly medium- to very coarse-grained; 5 per ce 10 per cent gravel. Sand: 80 per cent fine- to coarse-grained sand; 5 per silt; slightly plastic; 5 per cent gravel.	ent silt;
Sand: 85 - 90 per cent fine- to very coarse-grained s 5 - 10 per cent silt, decreasing toward the bottom; 5 10 per cent gravel, increasing toward the bottom. Sand: 90 per cent very fine- to very coarse-grained s	•
predominantly fine- and coarse-grained; up to 5 per ce silt; 5 - 10 per cent graval. Sand: 90 - 95 per cent very fine- to very coarse-grained; up to 5 per cent silt; up to 10 per cent gravel.	ined
Sand: 85 - 95 per cent very fine- to very coarse-grains and, predominantly fine- and coarse-grained, grading downward into mostly fine-grained; up to 5 per cent si up to 10 per cent gravel and rock fragments.	
Sand: 90 - 95 per cent very fine- to medium-grained swith some coarse- and very coarse-grains; less than 5 cent silt; 5 - 10 per cent gravel and rock fragments, decreasing to less than 5 per cent gravel toward the bottom.	

30,000 00,000	Lithology and <u>Water-Bearing Properties</u>
160	Sand: 90 per cent very fine- to very coarse-grained sand, with little medium- or coarse-grained; 5 per cent silt; 5 per cent gravel, predominantly fine-grained.
160	Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly fine-grained; 5 - 10 per cent silt, increasing toward the bottom; 5 per cent gravel; noncalcareous.
200	Gravelly Sand: 60 - 80 per cent fine- to coarse-grained sand; 5 per cent silt; 15 - 40 per cent gravel and rock fragments up to cobble size; boulder field encountered at this interval; samples become predominantly fine-grained sands, with up to 10 per cent gravel toward the bottom.
220 0	Silty Sand: 80 - 85 per cent very fine- to very coarse- grained sand; 10 - 15 per cent silt; slightly plastic in the middle five feet of the interval; up to 5 per cent gravel and rock fragments. Sand: 85 - 95 per cent very fine- to coarse-grained sand,
240	predominantly fine-grained toward the top; 5 - 10 per cent silt; up to 5 per cent gravel and rock fragments.
260	Silty Sand: 75 - 85 per cent: very fine- to very coarse- grained sand, predominantly fine-grained becoming predomin- antly fine- to medium-grained toward the bottom; 15 per cent silt, becoming 20 per cent toward the bottom; 5 - 10 per cent gravel and rock fragments.
280	

100	**************************************	Lithology and <u>Water-Bearing Properties</u>
320		Silty Sand: similar to above interval, but more coarse- grained sand; iron oxide stains begin to appear on dried samples; water encountered at 312 feet, and subsequently rose to 300.14 feet below ground level.
		Sand: 90 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; 5 - 10 per c mt silt; up to 5 per cent gravel. Sand: similar to above, but coarser-grained.
340	0. b. 7	Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 10 per
360	10 3/4"	cent silt; 5 per cent gravel.
380		Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- and coarse-grained; 5 - 10 per cent silt; up to 5 per cent gravel.
400		Sand: 90 - 95 per cent very fine- to very-coarse-grained sand, alternating layers of predominantly medical to very coarse-grains with predominantly fine- to madium-grains; 5 - 10 per cent silt; 5 per cent gravel; bottom five feet
420	Perforations	of interval is fine- and very coarse-grained sand.
440	1	

200	**************************************	Octobic, Cog	Sh Lithology and <u>Water-Beoring Properties</u>
460	7 геточеа.		
480	cut at 510° and		
500	10 3/4" a 0.72 - 8 5/8" Casing	•	Sand: 95 per cent very fine- to medium-grained sand; 5 per cent silt; few gravels; this interval becomes coarser-grained toward the bottom.
520	-		Silty Sand: 85 per cent very fine- to very coarse-grained sand, predominantly very fine- to fine-grained; 15 per cent silt; some gypsum, variety selenite; coarser sand grains are angular to subangular.
540	% . 0.0.7		Clayey, Silty Sand: 85 per cent very fine- to medium- grained sand, predominantly very fine- to fine-grained; 15 per cent silt; moderately plastic to plastic; becoming coarser-grained and less silty toward bottom of interval; this horizon serves as an aquitard between the two differ-
560	8		entiated aquifers.
580	2		Sand: 90 - 95 per cent very fine- to very coarse-grained sand, angular to subrounded; 5 - 10 per cent silt toward the bottom; very slightly plastic; 5 per cent gravel toward the top.
	Perforations		Sand: 95 per cent very fineto very coarse-grained sand, predominantly very fine- to medium-grained, becoming coarser toward the bottom; 5 per cent silt; non-plastic to very slightly plastic; some gravel and rock fragments toward the bottom.

/s	80/	0,000	Lithology and <u>Water-Bearing Properties</u>
620-	Perforations		Sand: 95 - 100 per cent very fine- to very coarse-grained sand, predominantly fine- to coarse-grained; less than Clavery Siles Sands of
660	W. O. D. 7		Clayey, Silty Sand: 85 per cent very fine- to medium- grained sand, predominantly very fine- to fine-grained, becoming coarser-grained toward the bottom of the interval; 10 - 15 per cent silt; moderately plastic. Sand: 90 - 100 per cent very fine- to medium-grained sand, some coarser grains: up to 5 per cent very fine- to medium-grained sand,
680	8 5.W		some coarser grains; up to 5 per cent silt; alternating layers of slightly- to moderately plastic sands with non-plastic sands; bottom of interval is moderately plastic to 699 feet, the total depth of the well.
700			

APPENDIX D

Lithologic Log of Test Hole H-2, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: West flank of the Sand Springs Range, on the alluvial fan sloping toward Fourmile Flat.

NEVADA STATE COORDINATES: N. 1,631,585.0; E. 543,132.0.

GROUND ELEVATION: 4,017 feet above sea a el.

TOTAL DEPTH: 780.0 feet below ground surface.

Sampled intervals: Cable-tool cuttings taken either every five feet or at a distinct clange of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-2 was drilled predominantly in subaerial and lacustrine sediments of Pleistocene to Recent age, and the section penetrated is possibly correlative to Lake Lahontan and post-Lake Lahontan stratigraphy as described by R. B. Morrison (U. S. G. S. Professional Paper 424-D, pp. 111-114, 1961). Description of the section is based on a binocular examination of the samples obtained by the cable-tool method of drilling. Procedure followed in describing the section is listed on page 98. The dominant lithology is fine- to medium-grained sand with varying amounts of clay, silt, and gravel. Several zones of cemented beach or near-shore deposits were encountered.

Some microfossils were found, almost always present in uniform, medium-grained sands.

Confined ground water was encountered in sand at a depth of 128.0 feet below ground surface. Overlying the sand aquifer is a possible beach or near-shore deposit of Lake Lahoutan which was cemented by a calcerous and siliceous material.

Į,	0000	Lithology and Water-Bearing Properties
		Sand: light-brown, with some green; 100 per cent very fine- to fine-grained sand, with medium grains, predominantly sub- rounded; non-frosted grains.
20-		Similar to 0 - 15 feet, but predominantly fine- to medium- grained sand; up to 40 per cent of sand grains nonquertmose, including olivine, biotite mica, hornblende, fine-grained acid and basic volcanics, zircon.
40	3/8" a.b	Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; up to 30 per cent nonquartzose; slightly plastic at 45 - 50 feet; 5 - 10 per cent gravel, including some with ellipsoidal shape; possibly a brach or near-shore deposit of Lake Lahontan.
60	5	Sand: 100 per cent very fine- to redium-grained sand, pre- dominantly subrounded; less than 10 per cent nonquartzose; some gravel toward bottom; microfossils present at 50 - 55 feet. Similar to above, but light-green-brown; 30 - 40 per cent
	0.0.7	nonquartzose. Similar to 50 - 60 feet, but subangular to subrounded; 25 per cent nonquartzose.
80	10 3A	Sand: 90 per cent very fine- to very coarse-grained sand predominantly subrounded; 25 per cent nonquartzose; 10 per cent subrounded to ellipsoidal gravel; possibly a beach or near-shore deposit of Lake Lahontan.
100	800	Sand: 100 per cent very fine- to medium-grained sand, pre- dominantly fine-grained, getting coarser-grained toward the bottom of the interval; up to 25 per cent nonquartgose; few gravels.
	8 5.6	Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly subangular; up to 25 per cent nonquartsose; 5 - 10 per cent silt, increasing toward the bottom; 5 per cent subangular gravel; alluvium. Similar to above, but more rounded sand and gravel; possibly
120	Perforations	beach or near-shore deposit of Lake Lahontan. Sand: olive green-brown; 100 per cent very fine- to very coarse-grained sand, predominantly medium- to coarse-grained and subrounded; 25 - 30 per cent nonquartzose; water encount-
140	3	ered at 128 feet and subsequently rose to 111 feet; 128-140: 5 per cent silt, slightly to moderately plastic, possibly contaminated by drilling mud: microfossils from 130-140 feet. Sand: light-brown; 95 per cent very fine- to medium-grained; 20 per cent nonquartsose; microfossils.

	•00 o	Lithology and Water-Bearing Properties
160-	0. B.	(145-160) Gravelly Sand: gray-green-brown; 80 - 85 per cent very fine- to very coarse-grained sand, angular to subrounded; 40 per cent nonquartzose; up to 5 per cent silt; 10 - 15 per cent angular to subrounded gravel.
180-	13 3/8"	Sand: gray-green-brown; 90 - 100 per cent very fine- to very coarse-grained sand, becoming very fine- to medium-grained and angular to subrounded at 165 feet; 25 - 30 per cent non-quartzose; 5 per cent silt from 160 to 165 feet; slightly plastic from 170 to 180 feet, possibly contaminated; 5 per cent gravel from 160-165; alluvium.
200-	10 3/4"0.0. 7	Sand: light-gray-brown; 95 - 100 per cent very fine- to med- ium-grained sand; 20 per cent nonquartzose, increasing to 40 per cent at 195 feet; up to 5 per cent silt. Sand: gray-light-brown; 95 per cent very fine- to very coarse- grained sand, angular to subrounded; 40 per cent nonquartzose;
220	8 5/8" a.b. 7	5 per cent silt; rock fragments, subrounded to ellipsoidal gravel from 205 - 210. Sand: gray-green-light-brown; 95 - 100 per cent very fine-to very coarse-grained sand, predominantly very fine-to medium-grained from 210 to 215 feet; 30 - 40 per cent non-quartzose; 5 per cent silt; few gravels; microfossils present at 210 to 220 and 235 to 242 feet.
240-	7	Gravelly Sand: gray-green-brown; 85 per cent very fine- to very coarse-grained sand; 40 per cent nonquartzose; 15 per cent gravel.
260	rforations	Sand: gray-green-brown; 95 per cent very fine- to coarse- grained sand, predominantly fine- to medium-grained; 15 - 20 per cent nonquartzose; 5 per cent gravel; microfossils present Sand: gray-green-brown; 95 per cent very fine- to coarse-
290	Parl	grained sand, predominantly very fine- to coarse- grained sand, predominantly very fine- to medium-grained; 15 - 25 per cent nonquartzose; 5 per cent silt; few gravels; very slightly plastic, may be apparent cohesion; microfossils present at 285 - 290 feet.
		Sand: gray-light-brown; 90 per cent very fine- to very coarse-grained sand, (cont.)

100,00		oo	Lithology and <u>Water-Bearing Properties</u>
			(cont. from 290 feet) predominantly very rine- to medium-grained; 15 per cent non- quartzose; 10 per cent silt; slightly to moderately plastic; microfossils at 300 - 305 feet.
320 340	Perforations		Similar to above, but up to 20 per cent nonquartzose; 5 per cent silt; nonplastic to slightly plastic; some gravel and rock fragments.
36 C	A"a 03	•	Similar to 315 - 350, but 100 per cent sand, microfossils present.
380	03		Sand: gray-green-brown; 95 - 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained from 360 to 445 feet; 20 per cent nonquart-zose, becoming 25 - 30 per cent at 450 feet; nonplastic to slightly plastic; up to 5 per cent gravel from 445 feet;
400			microfossils present at 445 to 450 feet.
420	8 5/8" 0.0.		
440		5, 5 •	

⁶ 00,00	Litholagy and Water-Bearing	Properties
F7		
460	Gravelly Sand: brown-green-gray; 80 - 85 per fine- to very coarse-grained sand, predoming to very coarse-grained; 50 - 60 per cant not 15 - 20 per cent gravel and rock fragments,	antly medium- nquartzose;
480	in size and become more subrounded to ellipse 465 feet, some show a calcareous and siliced hering to their surface; some slightly to me clay lumps present at 470 to 485; possibly or near-shore deposit of Lake Lahontan.	ous cement ad- oderately plastic
500	Sand: gray-green-brown: 95 - 100 per cent very coarse-grained sand, predominantly very grained; 15 per cent nonquartzose; slightly Gravelly Sand: olive-green; 85 per cent very coarse-grained sand, becoming 90 - 95 per cent feet; 25 per cent nonquartzose; slightly plagravel and rock fragments, some cement present	y fine- to medium- plastic. ry fine- to very ent sand at 505 astic; 15 per cent
520	fragments. Sand: olive-green-brown; 95 - 100 per cent coarse-grained sand, predominantly very fine grained; 20 - 25 per cent nonquartzose; slipplastic.	very fine- to e- to medium-
540	Similar to 515 - 525 feet, but plastic to very predominantly a sand lithology. Sand: gray-brown; 90 - 95 per cent very first grained sand, becoming coarser-grained towards.	ne- to medium-
560	predominantly subangular; 20 - 25 per cent is 5 per cent silt; up to 5 per cent gravel. Sand: gray-green-brown; 100 per cent very	nonquartzose; fine- to very
600	coarse-grained sand, predominantly very fine grained, becoming coarser-grained toward the interval; 15 - 20 per cent nonquartzose; not slightly plastic; up to 5 per cent angular gravel toward the bottom of the interval.	e bottom of n-plastic to
590		

600,00	Cosmo Cognic	Lithology and <u>Water - Bearing Properties</u>
	0 0	
620	8 5/8 a a -	Gravelly Sand: gray-green-brown; 85 per cent very fine- to very coarse-grained sand, becoming 60 per cent at 630 feet; 25 per cent nonquartzose, becoming 25 - 50 per cent at 630 feet, 15 per cent gravel becoming 40 per cent gravel at 630 feet, some of gravels are ellipsoidal; possible beach or near-shore deposit of Lake Lahontan.
660		Similar to above, but 15 - 20 per cent nonquartzose, 15 per cent gravel.
680		Sand: gray-green-brown; 95 - 100 per cent very fine- to very coarse-grained san predominantly very fine- to medium-grained toward L bottom of interval; 15 - 20 per cent nonquartrose; slightly to moderately plastic; up to 5 per cent gravel.
700		Gravelly Sand: brown-gray; 85 - 90 per cent very fine- to very coarso-grained sand; 20 - 25 per cent nonquartzose; moderately plastic from 695 to 705 feet; 10 - 15 per cent gravel.
720	Pertorations - 1	Sand: brown-gray; 90 - 100 per cent very fine- to very coarse-grained sand, angular to subrounded; 15 - 25 per cent nonquartzose; up to 5 per cent silt; ronplastic to slightly plastic; 5 per cent gravel.
740		

Lithology und <u>Water - Bearing Properties</u>		
760 "8/5 80 N3 30 81 780		Gravelly Sand: gray-brown; 80 per cent very fine- to very coarse-grained sand; 40 - 50 per cent nonquartzose; slightly plastic to plastic, decreasing in plasticity above and below the 760 to 765 foot interval.
,,,,,		
		•

APPENDIX E

Lithologic Log of Test Hole H-3, Project Shoal, Churchill County, No ada

GEOGRAPHIC DESCRIPTION: West flank of the Sand Springs Range, on the alluvial fan sloping toward Fourmile Flat.

NEVADA STATE COORDINATES: N. 1,627,331.86; E. 548,884.86.

GROUND ELEVATION: 4,232.2 feet above sea level.

TOTAL DEPTH: 480.0 feet below ground level.

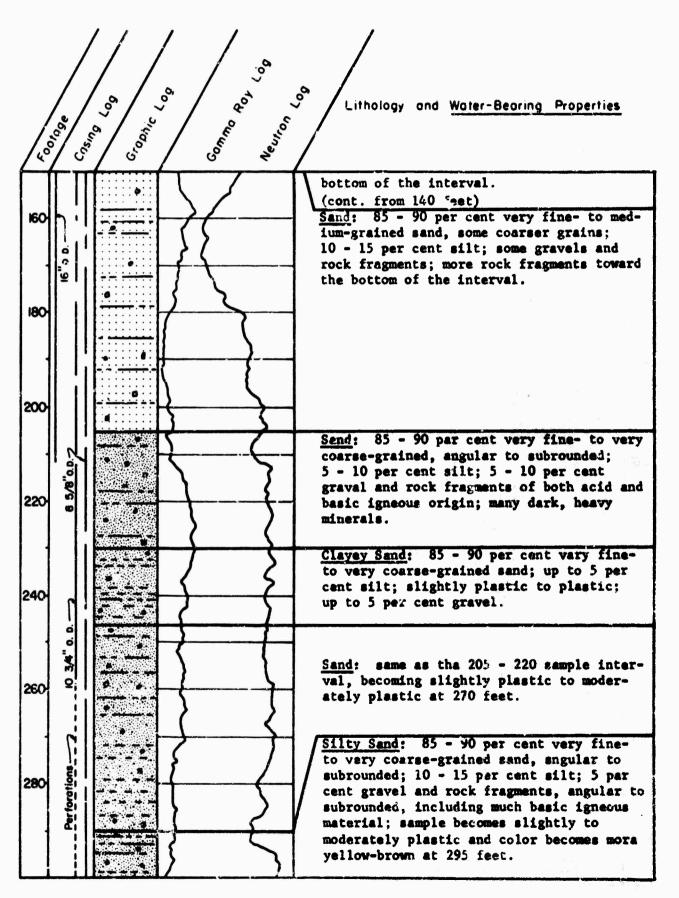
Sampled intervals: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

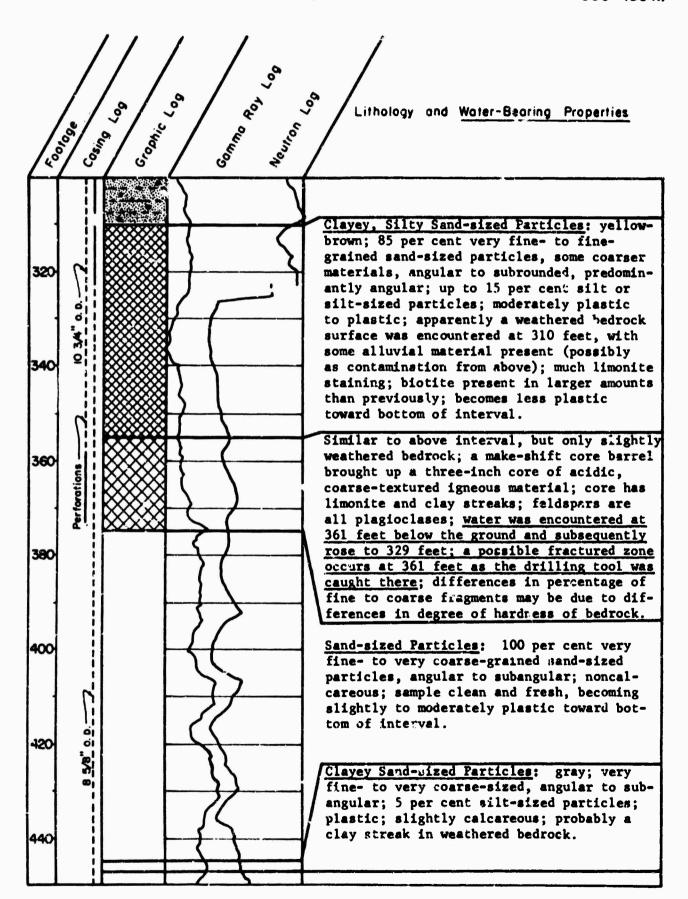
SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-3 was drilled in Quaternary alluvium, consisting of sands with varying amounts of clay, silt, and gravel, and in a weathered granitic bedrock of late Mesozoic (?) age. Description of the section is based on a binocular examination of the samples obtained by the cable-tool method of drilling. Procedure followed in describing the section is listed on page 98.

Confined ground water was encountered in slightly to heavily weathered granitic bedrock at a depth of 361.0 feet below the ground surface. Approximately 70 feet of silty, sandy alluvium and residual, clayey, silty, sand-sized particles derived from the weathering of granite bedrock overlie the top of the aquifer, which is probably a fractured and weathered zone in the bedrock.

NOTE: Gamma Ray - Neutron Log Horizontal scale reduced to 1/4 of Vertical scale





Į, Š	**************************************	, co, co, co, co, co, co, co, co, co, co	Sommo Por Cog	Lithology and <u>Water-Bearing Properties</u>
460	OPEN 8 5/8"00.7			Sand-sized Particles: very fine- to very coarse-sized, angular to subangular; 5 ~ 10 per cent silt-sized particles; moder-ately plastic toward the bottom of the interval.
				-

APPENDIX F

Lithologic Log of Test Hole H-4, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: East flank of the Sand Springs Range, in Fairview Valley, 149.50 feet N. 15° 01′ 18″ E. of HS-1.

NEVADA STATE COORDINATES: N. 1,622,285.67; E. 576,914.39.

GROUND ELEVATION: 4,241.92 feet above sea level.

TOTAL DEPTH: 935.0 feet below ground surface.

SAMPLED INTERVALS: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-4 was drilled in Quaternary alluvium consisting predominantly of sands with varying amounts of clay, silt, and gravel, and Tertiary (?) bedrock. Description of the section is based on a binocular examination of samples obtained by the cable-tool method of drilling. Procedure followed in describing the alluvial rock fragments is listed on page 98.

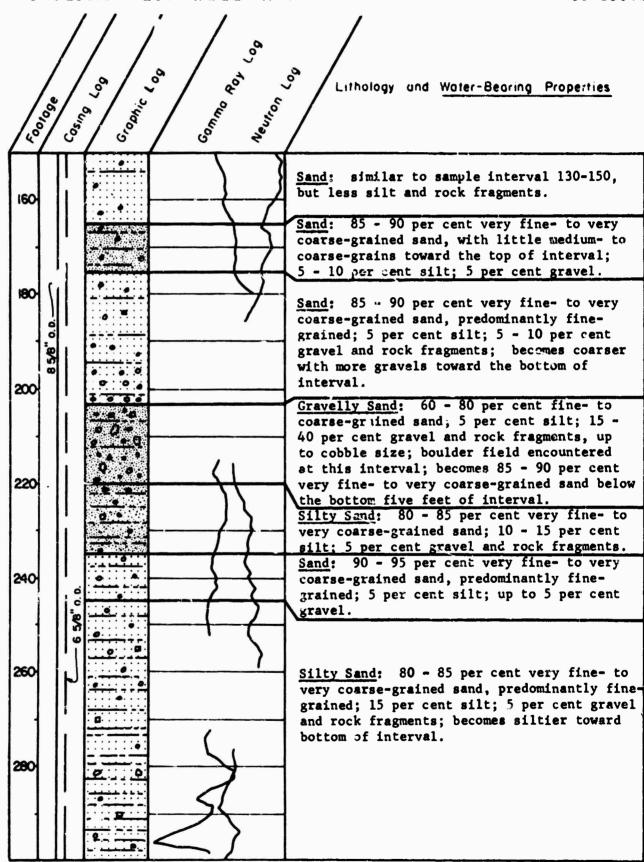
Confined ground water was encountered in sand at a depth of 310.0 feet below ground surface. Overlying the top of the sand aquifer is approximately 65.0 feet of fine-grained, silty sand. After drilling to a depth of 530.0 feet below ground surface a fine-grained, clayey sand was encountered, approximately 35.0 feet thick. This interval serves as an aquitard between the upper and lower aquifers, the latter consisting predominantly of sand, with a higher percentage of clay and silt than the upper aquifer.

At a depth of 813.0 feet below ground surface a distinct lithologic change was encountered, with subsequent changes in the sample of color, texture, percentage and nature of the accessory minerals, as well as an increase in the drilling time required per foot. The possibility of Tertiary bedrock from 813.0 feet to the bottom of the hole at 935.0 feet exists.

H-4 was later plugged at a depth of 708 feet below ground surface.

HYDRO	LOGIC TEST WELL H-	·4 0-15011.
\$0000 P	Cosmo Pop Cog	Lithology and <u>Water-Bearing Properties</u>
		Sand: 85 per cent fine- to medium-grained sand; 5 per cent silt; 10 per cent gravel; organic debris.
20		Silty Sand: 75 per cent very fine- to coarse grained sand, predominantly very fine- to fine-grained: 15 - 20 per cent silt; 5 - 10 per cent gravel.
40		Sand: 85 per cent fine- to very coarse- grained sand, predominantly medium- to very coarse-grained; 5 per cent silt, increasing toward the bottom of interval; 10 percent gravel, decreasing toward the bottom of
		interval. Sand: 80 per cent fine- to coarse-grained sand; 5 per cent silt; slightly plastic; 5 per cent gravel. Silty Sand: 70 per cent very fine- to very
60		coarse-grained sand, predominantly very fine- to medium-grained; 15 - 20 per cent silt; slightly plastic; up to 5 per cent gravel. Sand: 90 per cent very fine- to medium-
80 8		grained; less than 5 per cent silt; 5 - 10 per cent gravel; very slightly plastic. Silty Sand: 80 - 85 per cent very fine- to coarse-grained sand, predominantly very fine- to medium-grained; 10 - 15 per cent silt;
100		very slightly plastic toward top of interval; up to 5 per cent gravel. Sand: 85 - 95 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 5 per cent silt; 5 - 10 per cent gravel.
120		Sand: 90 per cent very fine- to fine-grained sand, some madium- and coarse-grained; less than 5 per cent silt; 5 - 10 per cent gravel and rock fragments.
140		Sand: 90 per cent very fine- to medium- grained sand, some coarser-grained; 5 per cent silt; 5 per cent gravel and rock fragments.

NOTE: Gamme May - Neutron Log Horizontal scale reduced to 1/4 of Vertical scale.



NOTE: Neutron Log plotted .2" right of actual reading.

HYD	RO	LOGI	C TEST	WELL	H-	4 300-450f1.
	000	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	Crophic Log	Joh ohmos	Neuron ,	Lithology and <u>Water-Beoring Properties</u>
320				\ \	}	Silty Sand: similar to interval 245-300, but more coarse-grained sand and gravel; water encountered at 310 feet and subsequently rose to 299.2 feet below ground level. Gravelly Sand: 80 per cent very fine- to very coarse-grained sand; up to 10 per cent silt; 10 - 15 per cent gravel; iron oxide stains begin to appear on dried samile. Sand: 85 - 90 per cent very fine- to very
340	5/8"0.0.	0	• (}(coarse-grained sand; 10 - 15 per cent silt; 5 - 10 per cent gravel. Sand: similar to above sample, but predominantly medium- to very coarse-grained and, 5 per cent silt.
360	88		\ 		\	Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 10 per cent silt, increasing toward bottom of interval; 5 per cent gravel, decreasing toward bottom of interval.
390		0				Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly medium-to very coarse-grained but becoming finer-grained toward the bottom of interval; 5 per cent silt; 5 per cent gravel.
400		6 5/8 0				Gravelly Sand: 80 - 85 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt; up to 15 per cent gravel. Sand: 90 per cent very fine- to very
420	erforations	2			1	<pre>coarse-grained sand, predominantly "ery fine- to medium-grained; 5 per cent silt; 5 per cent gravel. Sand: 85 - 90 per cent very fine- to very</pre>
440	Per les					coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt; 5 per cent gravel.
	1		÷:-:-:-			Sand: 95 per cent very fine- to medium- grained sand; 5 per cent silt.

NOTE: Neutron Log plotted 5" right of actual reading.

NOTE: Neutron Log plotted .25" right of octual reading.

NOTE: Neutron Log plotted .25" right of actual reading.

NOTE: Gamma Ray Log plotted .25" left of actual reading.

	**************************************	007 8 Jugo 15	So, Toy ownog	Lithology and <u>Water-Searing Properties</u>
920	OP & R			Sand: similar to 86¢ - 900, some slight plasticity or apparent cohesion to sample; heavy minerals increase toward the bottom of the interval; calcareousness increases toward the bottom of the interval; absence of gravels since 813 feet may be significant in indicating a non-alluvial sequence.
940				
				i.

APPENDIX G

Analyses of Water From Wells, Springs, and Intermittent Streams Inventoried for Project Shoal, Churchill County, Nevada

Analyses by Abbot A. Hanks, Inc., San Francisco, California

Quantities in Parts Per Million

Alkalinity Methyl Orange) (As CaCO ₃)	115 133 138 107 115	78 547 416 395 321	318 324 835 435	9325 545 1090 870	116 392 445
Bicarbonate (As CsCO ₃)	115 132 149 106 1370	78 541 406 327 316	313 317 820 473 423	3290 525 104 760	116 391 475
Carbonate (As CaCO ₃)	1-0-8	10 77 5	5 13 12	3980 48 84 25	3.08
Chloride	43 22 28 705 15950	33 4080 860 246 1760	1350 1450 2360 1110 2155	12760 46 1300 37	281 142 131
Suifate	53 39 42 150	1220 240 240 109 410	260 342 588 464 495	550 115 9	42 186 184
Silica	58 51 32 32	42 37 29 11 93	<u>4</u>	51 42 47 47	50 20 70
iron	404	0 0 0 8 8 8	000-m	3 analysi: 2 2 2	4 6 1 analysis
Potzesium	33 4 = 3 4	28 32 11 82	38 74 20 95 95	28. 32. 58. 58.	25 37 18 No a
Sodium		416 3745 1023 370 1415	1170 1160 2610 1490 2015	14250 280 1380 340	76 475 345
Magnesium	4 E 20 0 E I E	88 152 - 28	202	2 547	⊘ 4∞
Calcium	27 27 33 321 321	834-48	11 2 5	3 20 8	24 10 9
Tatal Solids (600° C)	282 265 338 1360 31930	704 9155 2230 970 3865	2910 3170 5660 3115 4820	35150 775 3120 934	260 918 990
рН	4.7 7.7 7.7 7.7	V 88 9 V 4 4 9 4 û	8.8 7.7 8.9 7.7	ତ ଛଞ୍ଚ ଅ. ବ୍ୟଠ	4.7.8 8.3 8.3
Analysis No.*	HS-1 H-4-1 H-2	- 0 to 4 to	۵۲ 80 9	2 <u>6.4</u> 2	16 17 18 19-22

^{*}Refer to Plate 9 for location of water point corresponding to each analysis number. **Upper aquifer.**
ILower aquifer.

APPENDIX G (Cont'd)

Analyses of Water From Wells, Springs, and Intermittent Streams Inventoxied for Project Shoal, Churchill County, Nevada

Quantities in Parts Per Million

Alkalinit (Methyl Orange (As GaGO ₂	152 153 108 108	290 143 340	107	71.	151	147	176
Bicarbenat (As CaCO _s	125 125 125	345 143 162 315	107	198	158	170	184
Carbonati (Ae CaGO _s)	d4	40-40	00	, «c	6 0	'n	<u>`</u>
Chloride	1090	257 39	:313	8	=	120	001
Suifate	58 76 1730	88 91 149 55	37	82	86	8	92
	4 84∞	4 %€60	51	24	<u> </u>	15	4
iren	analysis	-4445	<u>5</u> 8	-	~	ო	7
	๛๛๛๛ ฐ	<u>55</u> 7 e 9	4 rv	Ŋ	4	ω	٥
Sodium	88 139 110 55	86 107 39 235 106	95 44	18	74	13	98
Magnesium	108	<u> 4</u> rvaa	4 ₩	7	01	7	01
Calclum	8288	28 1 1 1 1 8	23	78	83	7	63
T'etai Seilde (600° C)	440 334 395 3995	645 200 342 342	288 253	363	398	402	388
Ha	7.88.87. 4.61.00	8.0 7.9 8.6 8.0	7.7	8.1	8.2		8.5
Analyala No.*	23 25 27-29	¥335333 ¥3353333	& O	Top4 Sample	Middle4 Sampie	Bottom4 Sample	Total ⁴ Sample

*Refer to Plate 9 for location of water point corresponding to each analysis number. 3Letters refer to surface water (intermittent streams).

These are ECH-D samples taken from elevations 3892 to 4120.

PART II

SHOAL OPERATIONAL STAGE

SECTION A

GEOLOGICAL, GEOPHYSICAL AND CHEMICAL.

INVESTIGATIONS OF THE SHOAL SITE,

SAND SPRINGS RANGE, CHURCHILL COUNTY, NEVADA

BY

PERSONNEL OF

NEVADA BUREAU OF MINES AND

NEVADA MINING ANALYTICAL LABORATORY

OF MACKAY SCHOOL OF MINES

UNIVERSITY OF NEVADA

RENO, NEVADA

1964

148.

PART II SECTION A

TABLE OF CONTENTS

	Page
Introduction	154
Acknowledgements	154
Geological Investigations	155
Geologic Mapping and Guidance	155
Objectives	155
Equipment and Instrumentation	155
Procedures	155
Results	155
Potassium-Argon Ages of the Granitic Intrusive Rocks	159
Introduction	159
Geologic Setting	159
Techniques	159
Sample Descriptions	163
Discussion	163
References Cited	164
Geophysical Investigations	165
Interpretation and Correlation of Geophysical Well Logs	103
With Geology for Instrument Holes PM-1, PM-2, PM-3,	
PM-8(ECH-D), and USBM-1	165
Objectives	165
Equipment and Operational Procedures	165
Results	167
PM-1	167
PM-2	171
PM-3	174
PM-8(ECH-D)	176
USBM #1	180
Summary and Conclusions	182
Bibliography	183
Temperature Measurements	184
Objectives	184
Equipment and Instrumentation	184
Operational Procedures	184
Results	188
Exposure of Minerals and Other Substances to High	
Pressure Shock Waves	193
Objectives	193
Description of Samples and Canisters	193
Operational Procedures	196
Results	202

		Page
Chemical Investigations		203
X-ray Spectrographic Analysis of Major Elements for Granite		
from Drill Hole ECH-D	• •	203
Introduction		203
Sample Locations and Sample Preparation		203
Equipment and Instrumental Conditions		205
Analytical Data		205
Silica (SiO ₂), Iron (Fe ₂ O ₃), Potassium (K_2 O),	• •	203
Calcium (CaO), and Titanium (TiO ₂)		207
Manganese (MnO)		207
Alumina (Al ₂ O ₃)		207
Composition Variation		211
Conclusions		211
References		211
race Elements in Shoal Granite Samples		214
Introduction		214
Procedures and Results		214
References Cited		223
MONOTORIO OLOGIA I I I I I I I I I I I I I I I I I I		~~~

FIGURES

				rage
1.	Post-shot geologic map of surface Ground Zero			158
	Generalized geology of the Sand Springs Range, showing			
	locations of samples for age determinations			160
	General location map USBM #1 and PM holes			168
	Generalized diagram: PM-1 showing fracture zones and dense rock			169
	Generalized diagram: PM-2 showing fracture zones and dense rock			172
	Generalized diagram: PM-3 showing fracture zones and dense rock			175
7.	a - geologic log of Drill Hole PM-8			177
	b - geologic log of Drili Hole PM-8			178
_	c - geologic log of Drill Hole PM-8	•	•	179
8.	Generalized Diagram: USBM #1 showing fracture zones and			
_	dense rock			181
	Shaft sinking schedule			185
	Drift advance schedule			186
	Location of temperature holes in shaft and drift			187
	Drift temperatures			189
	Temperature logs, Core Hole ECH-D, and shaft			190
	Nevada Bureau of Mine3 canister			195
	Richfield Oil Type A canister			197
16.	Richfield Oil Type B (Hoke Pressure Sample Container) canister.	•	•	198
	Penn State canister			199
	Location of canister holes in drift			201
19.	Percentage of SiO ₂ , Al ₂ O ₃ , K ₂ O, and CaO in Drill Hole samples.	•	•	212
20.	Percentage of Fe ₂ 0 ₃ , TiO ₂ , and MnO in Drill Hole samples	•	•	213
21.	Titanium variation: a) in pellets prepared from composite			
	samples; b) with Drill Hole sample	•	•	225
22.	Vanadium variation: a) in pellets prepared from composite			224
23	samples; b) with Drill Hole sample	•	•	226
23.	Manganese variation: a) in pellets prepared from composite			007
24	samples; b) with Drill Hole sample	•	•	227
24.	Copper variation: a) in pellets prepared from composite			220
25	samples; b) with Drill Hole sample	•	•	228
25.	Zinc variation: a) in pellets prepared from composite			220
26	samples; b) with Drill Hole sample	٠	•	229
20.	samples; b) with Drill Hole sample			230
27	Strontium variation: a) in pellets prepared from composite	•	•	230
21.	samples; b) with Drill Hole sample			231
28	Yttrium variation: a) in pellets prepared from composite	•	•	231
20.	samples; b) with Drill Hole sample			232
29.	Zirconium variation: a) in pellets prepared from composite	•	•	232
27.	samples; b) with Drill Hole sample			233
30.	Barium variation: a) in pellets prepared from composite	•	•	233
50.	samples; b) with Drill Hole sample	_	_	234
31.	Lanthanum variation: a) in pellets prepared from composite	•	•	234
	samples; b) with Drill Hole sample			235
32.	Cerium variation: a) in pellets prepared from composite	-	•	
	samples; b) with Drill Hole sample			236
33.	Gadolinium variation: a) in pellets prepared from composite	•	•	200
	samples; b) with Drill Hole sample	•	•	2 3 7

TABLES

												Page
1.	Specifications for underground photography	•	•	•	•	•	•	•	•	•	•	156
2.	Potassium-Argon Ages, Sand Springs Range, Nevada	•	•	•	•	•	•	•	•	•		162
	Temperature measurements in shaft and drifts											191
4.	Contents and positions of emplacement holes	•	•	•	•	•	•				•	200
5.	Core samples from ECH-D	•	•	•	•	•	•		•		•	204
6.	Instrumental conditions	•		•		•		•			•	206
7.	Percent composition Shoal granite sample	•	•	•	•	•	•	•			•	208
8.	Statistical analysis	•	•	•	•	•	•	•	•	•	•	210
9.	Project Shoal trace elements by X-ray emission s	pe	ct	ore	3C	opy	y .	•	•	•	•	216
							•	•				217
								•	•	•	•	218
							•	•	•	•	•	219
							•	•	•		•	220
	•						•	•	•	•	•	221
10.	Trace analysis of Shoal granite samples other th	an	X	-ra	ay							
	spectrographic						4					224

PLATES (In accompanying box)

- 8. Geophysical logs and geological log of Diamond Drill Hole ECH-D.
 9. Geophysical logs and geologic log, PM Hole No. 1.
 10. Geophysical logs and geologic log, PM Hole No. 2.

- 11. Geophysical logs and geologic log, PM Hole No. 3.
- 12. Geophysical logs and geologic log, USBM Hole No. 1.

INTRODUCTION

Following the exploration work leading to the selection of the site for the Shoal event, a proposal for the continued participation of the University of Nevada was made in December 1962 and was accepted. This section describes geological mapping and guidance, intrusive rock age determinations, interpretation of geological and geophysical well logs, temperature measurements, exposure of minerals and other substances to high pressure shock waves, and chemical studies of the Shoal granite.

The work was under the overall supervision of S. E. Jerome and was carried on primarily by L. Agenbroad, L. Beel, R. Horton, S. Jerome, J. Schilling, H. Vincent, A. Volborth, and P. Weyler.

ACKNOWLEDGEMENTS

Acknowledged with pleasure is the cooperation of many individuals in the Atomic Energy Commission, Sandia Corporation, Fenix and Scisson, Reynolds Electrical and Engineering Co., Lookout Mountain Laboratory, and Holmes and Narver, Inc.

Acknowledgement also is made of the excellent work of R. Paul and R. Wilson on preparing illustrations, by J. Murphy, S. Owen, R. Tilman and B. Fabbi on sample preparation, and by H. Mossman and J. Grimes on typing the manuscript for reproduction. 3. Chuba checked the chemical calculations and compiled the statistics.

GEOLOGICAL INVESTIGATIONS

Geologic Mapping and Guidance by S. E. Jerome

OBJECTIVES

Pre- and post-shot geologic mapping and photography of all underground workings was proposed to determine changes caused by the shot and to pro-vide data on the geologic characteristics of a relatively unaltered granite body.

Post- hot surface mapping was proposed to determine changes caused by the shot.

It was agreed to provide such geologic guidance as the Atomic Energy Commission and its contractors might reasonably request.

EQUIPMENT AND INSTRUMENTATION

No equipment or instruments were employed for the geological mapping other than the usual Brunton compasses, tapes, map cases, transits, aerial photographs, etc. For photographing the walls of the east drift a flatcar was modified to carry two Hulcher cameras and essential lighting equipment.

PROCEDURES

To minimize interference with the mining contractor, it was arranged that routine geologic mapping of the shaft and of the headings, as well as drill hole logging, would be done initially by Holmes & Narver and finally by Fenix & Scisson personnel. The work, especially that in the headings, was of such good quality that NBM staff was concerned only with specific fault problems and with over-all check work.

With the approval of Major Shelton, DOD, arrangements were completed with S. Williams of Lookout Mountain Laboratory for pre-shot photography of both walls of the east drift, washed down for the purpose. The photography could not be accomplished before the cables had been hung, so the fields of view have obstructions. Mr. Williams' specifications for this photography are included in Table 1.

Two days after the shot the immediate area around Ground Zero was mapped in detail, and several weeks later the entire bulldozer grid and a large area around it were covered in reconnaissance fashion using aerial photographs for mapping purposes and tote-gotes for transportation.

RESULTS

Detailed geological maps, drill logs, sections and shaft plans have been prepared by and are available from Fenix and Scisson. A generalized interpretation of the geology by NBM staff pertinent to Ground Zero is presented on Plate 5 in the plan of the east and west drifts and the cross section.

TABLE 1 PROJECT SHOAL

SPECIFICATIONS FOR UNDERGROUND PHOTOGRAPHY (S. Williams - Lookout Mountain Laboratory)

Distance from C	amera Wall (A _l	pprox.)		60 inches
Coverage of Wal	1			7'6"
Overlap	Average			30%
Overlap	alculated			33 1/3%
Scale	Negative	(Approx.)		1/40
Scale	Print (Enla	rged 4 Areas)	(Approx.)	1/10
Number of Expos	ures	(Approx.)		203
Length of Mosai	c (with ENLARG	GED prints)		101.5 ft.
Length of North	Wall covered			1015 ft.
Length of South	Wall covered			1000 ft.
Height of Camer	a	(Approx.)		3 1/2 ft.
Angle of Covera	ge			74°
Focal Length of	Lens			38 mm.
Type of Camera				Hulcher
Desirable f-sto	P			f11-f16
Shutter Speed				1/150 to 1/200
Film				Tri-X
Interval Flatca	r will be move	ed		5 ft.
Number of Light	s 30 volt	, 250 watts		10 each Bank
Number of Light	s (IF Par 28	150 watt with	Transformer)	10 each Bank
Current Require	d = 115 to 126	0 volts		Minimum 30 amp Desirable 60 amp
Current Require	d = 32 volts			640 ampere hrs.
Actual size of	negative			2 1/2 V, 2 1/4 H.

The lower part of the shaft encountered a northwest trending fault zone, designated "F" fault, not exposed on surface. In the east drift "No. 1" fault zone represents two northeasterly trending faults that apparently moved a segment of "F" fault north. "No. 2" fault zone also consists of two main northeasterly trending planes with the ground between showing both northeasterly and northwesterly elements. The northeasterly trending zones were mapped on surface in the bulldozer grid south of the access road but were not projected north of the road because the granite is well exposed and relatively undisturbed where these faults should pass through.

It has been suggested that "F" fault has been set north by No. 2 fault zone and may be the same as "E" fault. As of now this is an academic question and could not be resolved without additional drilling. "C" fault was encountered as expected, and "E" fault was proven to exist as predicted by two holes, B-2 and B-3, drilled northeast near the working point.

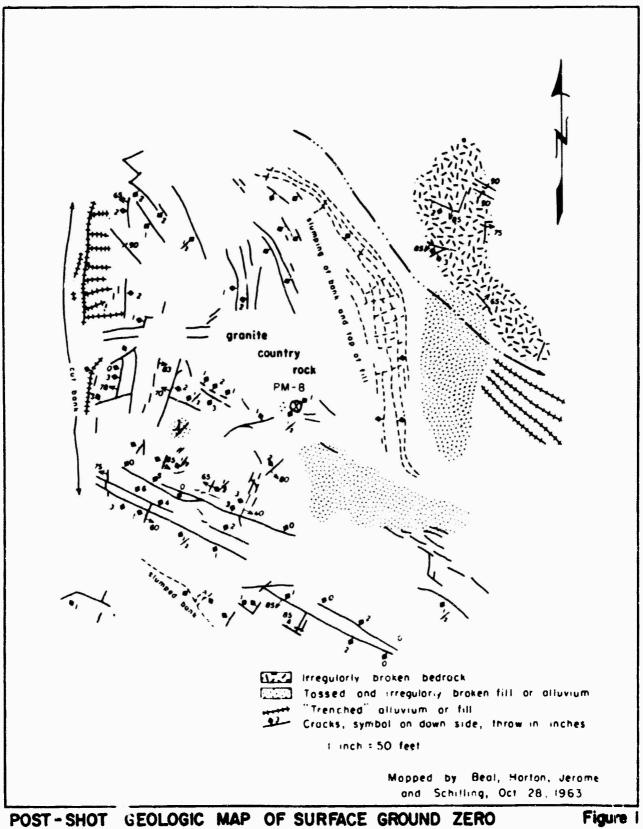
Drilling and underground work indicate that the broken ground encountered in ECH-D between 1,440° and 1,675' is the combination and intersection of "C" and "E" faults.

Contact prints of the drift wall photography have not been assembled in a mosaic. Because of the distortion of the sides caused by the wide-angle lenses, it is doubtful if a mosaic would be useful. In the event of re-entry and re-photography of the walls, the photographs on hand will be most useful for comparison. Except for additional detail nothing is shown by the photographs that differs markedly from the geological maps.

Post-shot mapping of surface Ground Zero was completed at a scale of 1"=50'. (See Figure 1.) Displacements up to 6 inches along the northwest joint system were most striking but no consistent step p ttern was evident. Joints striking northerly and dipping between 40° and 70° east were opened and had displacement. Opening of the fracture cleavage was evident in only a few places, but it contributed to scaling and crumbling of the granite on some rounded surfaces. Fill in the roadbed and on the drilling pad for ECH-D etc., as well as the wind-blown silt, locally was disturbed by the shock.

Shock effects observed up to 3,500 feet from surface Ground Zero include:

- 1. Substantial rock slides on the steep west face of the range and smaller rock falls elsewhere.
- 2. Adjustment on pre-existing joints and fracture cleavage, although this diminished rapidly from Ground Zero.
- 3. Opening of, and adjustment along, irregular new fractures subparallel to the conformation of massive granite outcrop surfaces. This resembles exfeliation weathering phenomena. This effect also diminished rapidly from Ground Zero.



POST-SHOT GEOLOGIC MAP OF SURFACE GROUND ZERO

4. Float blocks of aplite and granite show adjustment with relation to the surrounding soil and in some cases rotation and tilting. These inertial effects naturally are better expressed on sloping surfaces rather than level ones. Blocks of aplite, because of their resistance to weathering, provide the best evidence of movement.

All available drill core from Shoal has been stored by the Nevada Bureau of Mines at Reno.

Potassium-Argon Ages of the Granitic Intrusive Rocks by John H. Schilling

INTRODUCTION

As part of the geologic study of the Sand Springs Range for the Atomic Energy Commission described in this volume, six potassium-argon age determinations were made on biotite from several varieties of the granitic rocks in the Range. Two (AD-6 & 7) of the determinations were run at a later time to clarify the results of the first four determinations.

GEOLOGIC SETTING

The generalized geology of the Sand Springs Range is shown in Figure 2. The granitic intrusive rocks in much of the Range are described in detail in Part I, but since the southernmost intrusive masses are not covered, they are described briefly below.

Several small bodies of granodiorite intrude the Jurassic metamorphic rocks in the hills at the south end of the Range. At the Nevada Scheelite (Leonard) mine, a granodiorite stock about a mile in diameter intrudes the metamorphic rocks. Here, the granodiorite is an equigranular, medium-grained rock consisting of 55 to 65 percent plagiociase (An₂₅₋₃₅), 10 percent microcline, 15 percent quartz, 5 to 15 percent biotite, and 0 to 5 percent hornblende. Biotite is the dominant accessory mineral, in contrast to the granodiorite phase of the main intrusive body in the range which is hornblende-rich. Large tactice masses consisting of scheelite and skarn minerals occur in a 500-foot-thick limestone unit in contact with the intrusive. Over 5,500,000 pounds of WO₃ (tungsten oxide), valued at about \$12,000,000, have been produced from these deposits.

TECHNIQUES

In collecting the five rock samples, an attempt was made to obtain fresh and unaltered material. This was possible except for sample AD-2 which was badly altered and weathered.

The Nevada Bureau of Mines prepared the biotite concentrates from the rock samples except for the biotite concentrate from AD-6 which was hand-picked from the rock in the field. The samples were first run through a "chipmunk" jaw crusher and the minus 1/4-inch material passed through rolls and a disk pulverizer; an attempt was made to unlock the biotite from the other mineral components with as little actual crushing of the biotite as possible. The plus 60 mesh (0.250 mm) and minus 80 mesh (0.177 mm) material was discarded; the remaining pulverized rock was then run through

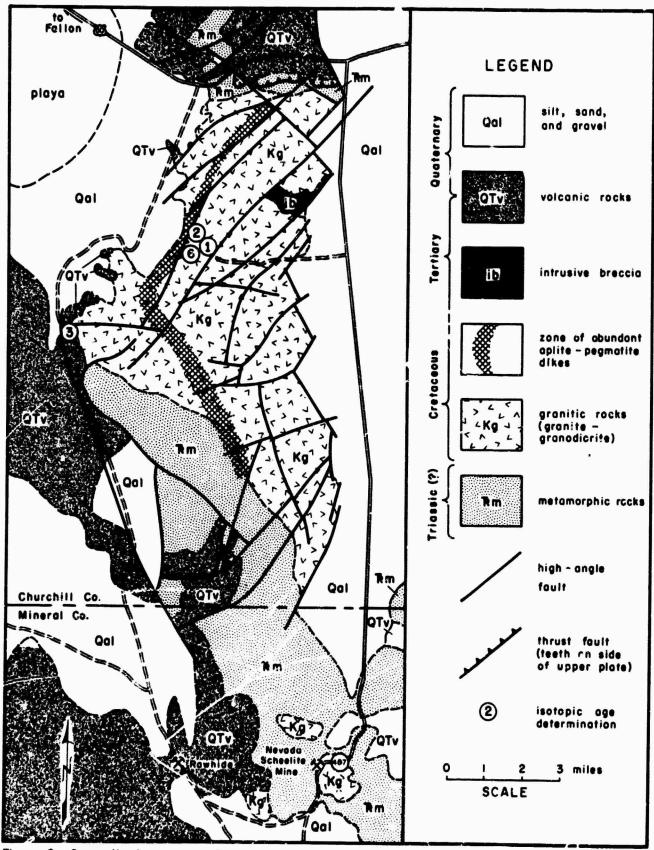


Figure 2. Generalized geology of the Sand Springs Range, showing locations of samples for age determinations.

electrostatic and Frantz magnetic separators and heavy liquids, to concentrate the biotite. The biotite in the concentrates from AD-1 and AD-4 was fresh (unaltered) in appearance with a small amount of separate chlorite grains as contaminants; the biotite concentrates from AD-3 and AD-7 also were fresh (unaltered) and contained separate grains of normblende and some chlorite (H.W. Krueger, written communication). In contrast, the biotite from AD-2 was not fresh but was considerably altered to chlorite. The biotite from AD-6, which did not go through this concentrating process, was coarse and showed only slight alteration to chlorite.

Geochron Laboratories, Inc., Cambridge, Massachusetts, performed the potassium-argon age determinations. Table 2 gives pertinent data for each of the determinations. The argon analyses were performed by isotope dilution and mass spectrometry, the potassium analyses by flame photometry. The following discussion of Geochron's techniques was prepared by Harold Krueger, Technical Director, Geochron Laboratories:

"The system for extracting argon consists of a nickel furnace, electrically heated and containing sodium hydroxide flux, a cold trup to remove water vapor, and a copper oxide trap to convert hydrogen into water. The Ar³⁸ spike is admitted through a central pipetting system directly into the fusion line during the sample fusion. After the sample fusion is complete, the spike admitted and the water vapor removed, the remaining gas is exposed to hot sponge titanium and finally sealed off on charcoal prior to mass spectrometric analysis.

"The mass spectrometric analyses of argon are performed on a spectrometer of the Reynolds type utilizing a glass tube. The mass spectrometer tube employs a variable electromagnet for scanning and a vibrating reed with a 10^{11} ohm resister for measuring the ion currents. All analyses are performed under dynamic conditions.

"The potassium analyses are performed by flame photometry on a Beckman DU Spectrophotometer. Duplicate analyses of all solutions are performed. The solutions are prepared by decomposition of the sample in HF and H₂SO₆.

"All argon and potassium determinations are performed in duplicate on separate aliquots of the sample. Each of the three different spikes used in the argon analyses has been calibrated more than ten times during the past year. The errors quoted on these age determinations are 95% probability limits based upon several hundred duplicate argon and potassium analyses."

The following constants were used in calculating the age:

$$\lambda_e = 0.585 \times 10^{-10}/\text{years}$$

$$\lambda_{\beta} = 4.72 \times 10^{-10}/\text{years}$$

$$K^{40}/K = 1.22 \times 10^{-4}$$

POTASSIUM-ARGON AGES, SAND SPRINGS RANGE, NEVADA Determinations by Geochron Laboratories TABLE

Sample No.	Rock Type	Mineral	₩ %	Ar ^{40*} (ppm)	Ar ^{40*} /Total Ar ⁴⁰	Apparent Age (m.y.)
AD-1	Granite	Biotite	5.54 5.40 Av. 5.47	0.0322 0.0312 Av. 0.0317	0.500	79.6± 2.0 [∆]
AD-2	Aplite-Pegmatite	Biotite	$\frac{2.76}{2.73}$ Av. $\frac{2.73}{2.74}$	0.0058 0.0056 Av. 0.0552	0.233 0.158	31.5± 3.0∆
AD-3	Granoliorite	Biotite	2.65 2.67 Av. 2.00	0.0148 0.0146 Av. 0.0147	0.010	75.0± 2.0△
AD-4	Granodiorite	Biotite	6.40 6.43 Av. 6.42	0.0412 0.0409 A v. 0.0410	0.056 0.074	87.5± 1.0 ^Δ
AD-:j	Aplite-Pegmatite	Biotite	$\frac{5.53}{5.55}$ Av. $\frac{5.55}{5.54}$	0.0248 0.0280 Av. 0.0254	0.089	65 ± 4 A
AD-7	Granodiorite	Biotite	7.22 7.20 Av. 7.21	0.0440	0.749	83.6± 3.50

^{*} Indicates radiogenic component. A Indicates analytical reproducibility based on replicate analyses of all potassium and argon determinations.

SAMPLE DESCRIPTIONS

- (AD-1) GRANITE: Fresh, porphyritic biotite granite, typical of the granite of the main granitic body; from a prominent outcrop several feet above the surrounding flat, about 200 feet east-southeast of the Shoal shaft and 1,235 feet N. 60° E. of the southwest corner of Sec. 34, T. 16 N., R. 32 E. (see Figure 2 and Plate 5).
- (AD-2) PEGMATITE: Weathered, biotite-rich pegmatite; from an aplite-pegmatite dike exposed in a trench 1,505 feet N. 3° W. of the southeast corner of Sec. 33, T. 16 N., R. 32 E. (see Figure 2 and Plate 5).
- (AD-3) GRANODIORITE: Fresh, hornblende-biotite granodiorite, typical of the granodiorite of the main granitic body; from the southwest side of Fourmile Canyon, in the southwest quarter of Sec. 11, T. 15 N., R. 31½ E., where the canyon trends southeast, is narrow, and has vertical walls (see Figure 2).
- (AD-4) GRANODIORITE: Fresh, biotite granodiorite from the northeast margin of the stock at the Nevada Scheelite mine (see Figure 2); from the north side of the canyon in which the main road to U. S. Highway 50 is located, at the line separating R. 32 E. and R.33 E. which is one-half mile east of the mine.
- (AD-6) PEGMATITE: Fresh, biotite-rich pegmatite; from an aplite-pegmatite dike exposed in a trench 790 feet S. 24° E. of the southeast corner of Sec. 33, T. 16 N., R. 32 E. (see Figure 2 and Plate 5).
- (AD-7) GRANODIORITE: Same as AD-4; from within a few feet of AD-4.

DISCUSSION

The geologic field evidence suggest that the granite and granodiorite of the main granitic body in the Sand Springs Range probably are two phases of the same intrusive, that they were emplaced at about the same time, and that the grandiorite is younger. The interpretation is supported by the results of the age determinations of granite (AD-1) and granodiorite (AD-3) from the main granitic body which gave ages of 79.6 m.y. and 76.0 m.y. respectively.

In contrast, the age determinations (AD-4 and AD-7) of the granodiorite from the small stock at the Nevada Scheelite mine gave ages of 87.5 m.y. and 83.6 m.y. respectively suggesting that this body is significantly older than the granodiorite of the main mass which it resembles mineralogically and texturally. No direct geologic evidence was found either to support or contradict this older age. The second determination (AD-7) was run from a separate, yet closely-spaced, rock sample to provide a check. The close agreement of the two determinations strongly supports this older age. If both the main granitic body and the Nevada Scheelite stock are parts of the same intrusive mass as seems probable, the older ages of AD-7 and AD-4 probably are due at least in part to their position in the upper and outermost portions of the mass, which would have solidified and cooled

first, in contrast to the central portions of the mass from which AD-1 and AD-3 were taken, which would have solidified and cooled much later.

The aplite-pegmatite dikes appear to have been intruded as a late-stage differentiate from the still plastic portions of the granitic (granite-granodiorite) body. This interpretation does not agree with the age determination (AD-2) of biotite from one of the dikes which gave an age of 31.5 m.y. --- much younger than the ages from the granite and granodiorite. However, this biotite shows considerable alteration to chlorite; such alteration can lead to a younger age which may or may not be indicative of the date of alteration (H. W. Krueger, written communication). For these reasons, the isotopic age was suspect and an attempt was made to find a dike containing unaltered biotite. After a lengthy search, biotite that showed only slight alteration was obtained. This biotite (AD-6) gave an age of 66 m.y. Because of the slight alteration to chlorite, this age probably is somewhat younger than the true age of the biotite, however it does support the interpretation that the dikes are late-stage differentiates.

In summary, both the isotopic age determinations and other geologic evidence indicate that the main granite-granodiorite body, the stocks, and the aplite-pegmatite dikes of the Sand Springs Range all were emplaced during a single period of igneous activity lasting for at least 10 million years during Late Cretaceous time.

REFERENCES CITED

Geehan, R. W., and Trengove, R. R., 1950, Investigation of Nevada Scheelite, Inc., deposit, Mineral County, Nev.: U. S. Bur. Mines R. I. 4681, 13 p.

Ross, D. C., 1961, Coology and mineral deposits of Mineral County, Nevada: Nev. Bur. Mines Bull. 58, 98 p.

GEOPHYSICAL INVESTIGATIONS

Interpretation and Correlation of Geophysical Well Logs With Geology For Instrument Holes PM-1, PM-2, PM-3, PM-8, ECH-D, and USBM-1 by Larry Agenbroad

OBJECTIVES

The purpose of this study was to make interpretation of geophysical well logs run in the various instrumentation holes, and to correlate this information with the geology. Geologic information was obtained from analysis of rotary drill cuttings and several short drill core intervals. The ultimate objective was to analyze and correlate information from oil field logging methods with the geology in an area of igneous rocks in an attempt to utilize these methods in the determination of physical characteristics of crystalline rocks, such as fractured areas, density of fracture patterns, etc.

EQUIPMENT AND OPERATIONAL PROCEDURES

A brief description of the working principles of the various logs follows. Persons interested in a more detailed explanation of principles involved, methods of interpretation, etc. are referred particularly to Schlumberger Well Logging Document No. 8.

Caliper log: the caliper log is obtained by an instrument consisting of two pads applied to opposite sides of the bore hole by a spring system. The recording of the distance between the outer faces of the pads is the caliper log.

Temperature log: a continuous recording of temperature versus depth in the bore hole.

Sonic log: a record of the time required for a sound to travel through a definite length of formation. The velocity of sound is affected by the rock material, porosity, pressure, fluid content, fracture planes, etc. Dense, or high velocity, rock is reflected by right excursions of the sonic log curve.

Radiation log: the radiation log is composed of the Gamma Ray and Neutron logs. The gamma ray log measures the natural radioactivity of the formation. The neutron log is useful in determining the presence of hydrogen bearing substances, (water, oil, gas, etc.). The neutrons from an emission source are slowed down and captured by the hydrogen atom, thus the neutron counting rate increases as the hydrogen concentration decreases.

Formation Density log: this log is based on the scattering of gamma rays and aids in determining the bulk density of a formation. Left extensions of the curve indicate lesser density.

Electric log: composed of SP log and three Resistivity logs based on different electrode spacings. The spontaneous, or self, potential (SP) log is a record of natural potential difference between an electrode at the surface, and a moving electrode in borehole. The resistivity logs measure the earth resistivity, dense portions having higher values.

Microlaterlog: a resistivity measuring method used to determine permeable beds in hard or well consolidated formations; it is also a valuable tool in thin bedded formations. The electrodes are mounted very close to each other, measuring small volumes of formation and giving close control on formation contacts. Low resistivity readings are representative of zones of fracture in crystalline rocks, especially if they contain water.

Frac-Finder log: this method measures the amplitude of the acoustic signal reflected from any interface where there is a large density change. At such interfaces a portion of the signal is reflected and a lesser amount reaches the receiver than if fractures were not present.

Micro-Seismogram: method of recording acoustic amplitude with time and depth. It is a continuous recording of the oscilloscope presentation of the full acoustic signal on a time-amplitude graph. The received acoustic signal is presented as full wave train of light or dark bars representing each half cycle of the wave. The multiple travel paths of the acoustic signal in fractured formation results in phasing and splitting of cycles causing reflection patterns to be superimposed on the direct signal from transmitter to receiver.

*All holes were drilled by Brinkerhoff Drilling Company, Denver, Colorado. Rotary drill cuttings were taken at five-foot intervals during irilling operations on all holes. These samples were reduced in a Jones sample splitter, maintaining representative samples, and mounted with clear cement on four-foot-long sludge boards. The cuttings were then studied under a binocular microscope for alteration and mineralization features and maximum sludge grain size. Diamond drill core intervals obtained from the holes were logged and drilling rates were computed from the daily drillers reports.

Standard geophysical logs were run in the PM (Particle Rotion) holes by Schlumberger Well Surveying Corp. Sonic, Formation Density, Gamma Ray-Neutron, Electric, Microlog, and Microlaterlogs were obtained in all the PM holes, with the exception of PM-8. The proximity of PM-8 to ECH-D, in which logs had previously been obtained, led to a decision to omit logs from this instrument hole. In addition to the above mentioned logs, a temperature survey was run in PM-1.

The USBM #1 hole was logged by Welex, a division of Haliburton Company. Acoustic Velocity (including caliper log), Radioactivity, Frac-Finder, Spontaneous Potential, and Micro-Seismogram surveys were obtained in this hole.

Though several types of rock bits were used in drilling operations, one standard type was used in the majority of drilling. In conversation with

^{*} With the exception of ECH-D.

C. Lockhart, Brinkerhoff representative, it was concluded that the bit difference should not notably affect the sludge grain size, with the possible exception of toothed bits used in opening the holes, whereas button bits were used at depth.

Holes PM-1, 2, 3 are located on the circumference of a circle of 2,000 foot radius, centered on the point of device emplacement. PM-8 is located fifteen feet WSW of ECH-D, and USBM-1 is located between ECH-D and PM-3. (See Figure 3.) With the exception of PM-2 which cuts andesite dikes, the rock type encountered in all holes is granite of the "ground zero" type encountered in ECH-D, and except for faults and joints and possibly some small aplite-pegmatite dikes, is considered to be uniform and homogeneous.

RESULTS

In analysis of the geophysical logs, the terms "major" and "minor" fracture zones are used. A major zone of fracture refers to an interval several feet in width (or depth) which contains two or more fractures, as evidenced by geophysical logs. It is generally a continuous interval of increased hole diameter on the caliper logs. Cored intervals supply evidence that these zones are considerably more fractured than is indicated by the geophysical logs. A minor zone of fracture is one in which there is a single, "narrow", correlation across the geophysical logs. The core commonly shows several individual fractures within these "minor" zones.

The depths given on all logs are measured from the Kelly Bushing of the drill rig.

The micrologs were not utilized in analysis of the instrument holes.

Interpretation of well logs for individual holes follows:

PM-1 See Plate 9 and Figure 4

Location: N. 1,618,717.83 - E. 556,030.63

(U.S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: vertical

Collar Elevation: 5,358.03'

Total Depth: 1,339' Ground Level (G.L.), 1,345' Kelly Bushing (K.B.)

Date Begun: 3/10/63
Date Completed: 3/25/63

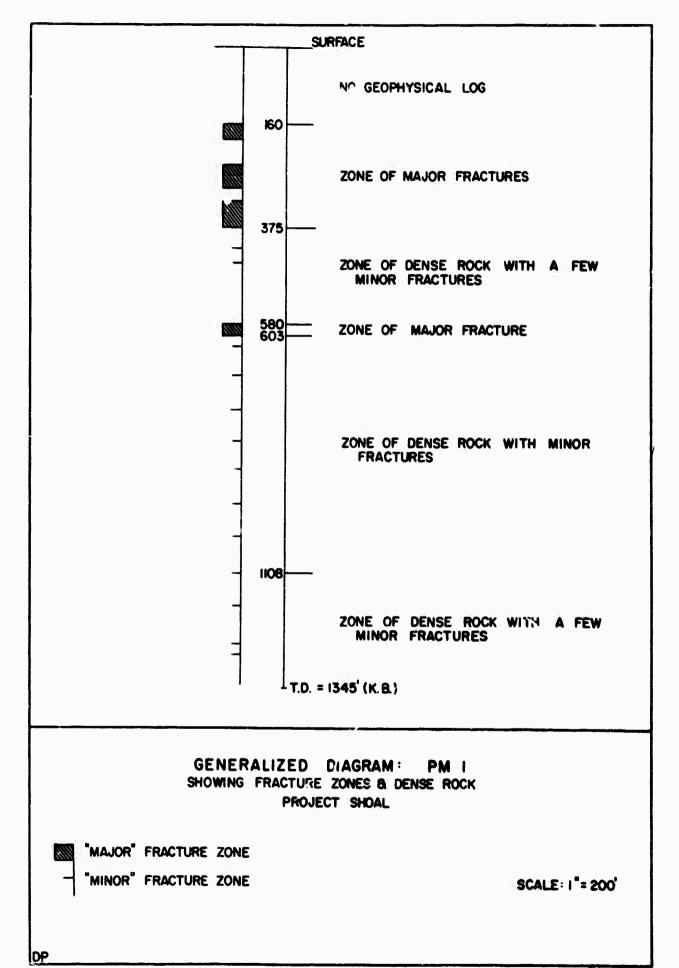
Drilling Rate: 6.67 min./ft. (Actual Drill Time)

6.84 min./ft. (Drill Time plus reaming of core intervals)

Correlation of the geophysical logs shows four major zones of fracture in the upper part of the hole, and an additional twenty-six minor zones of fracture. Comparison of geophysical evidence with cored intervals shows that there are fractures present which are not indicated by geophysical logging. Core analysis also shows that in areas which are indicated as one minor zone of fracture on geophysical logs, as many as 5-10 fractures exist in the core.

• PM 2 PM 8 % ECH D OUSBM# SHAFT • PM 3 • PM I GENERAL LOCATION MAP USBM*I AND PM HOLES PROJECT SHOAL SCALE: I" = 1000'

Figure 3



Logging started at approximately 150 ft. depth on most PM-1 logs. As interpreted from the various logs, a major zone of fracture containing four to nine fractures extends from 160'-190'. This zone shows hole diameter in excess of 15 inches in an interval drilled with a 12 inch bit, indicating a large degree of caving and washout, as might be anticipated in a highly fractured zone.

A second major fracture zone is indicated in the interval 243'-290', with an undetermined number of fractures present in this zone. Bulk density curves go off scale on minimum values in this interval; caliper curves also go off scale (+16").

A third major fracture zone occurs at 320'-375', with up to 16 fractures indicated within the zone. The density curve goes off scale (minimum); the caliper shows +16" hole diameter; and maximum interval transit times are reached in this fracture zone.

From 375' to 570' the rock appears to be dense, with three minor fracture zones at 420', 433', and 446'. Core taken within this interval exhibits no fracturing; the caliper log indicates relatively "tight hole" conditions, and the resistivity, density, neutron, and transit time curves hold steady except in the above mentioned minor iracture zones.

The fourth major fracture zone lies from 580'-603' with as many as 7 fractures indicated within the zone. Core analysis in this interval shows 4 fractures, with less than 50% core recovery. The density curve goes off scale (minimum) twice within this interval. Drillers logs record a loss of 79 barrels of drill fluid in this interval.

Five minor fracture zones are within the interval from 620'-690'. at 628', 650', 657', 671', and 690'. This interval is followed by one of apparent unfractured rock to 762'. The caliper log shows some minor irregularities in this interval, but is not backed up by the geophysical logs. In general, "tight hole" conditions are reached, with less than 2" increase of hole diameter over bit size.

Four minor fracture zones lie between 762' and 830'; at 763', 779', 810', and 830'. This interval is followed by unfractured rock to 890', with caliper log recording tight hole conditions of less than one inch over bit size.

From 890'-960' four minor zones of fracture occur, causing local bore hole enlargement. The fracture zones occur at 890', 910', and 960', with drillers logs recording a loss of 225 barrels of drilling fluid in the interval. This interval is followed by one of unfractured rocks to 1,028'.

Another zone, from 1,028'-1,108' contains five minor fractures, and causes an area of borehole enlargement in an essentially tight hole environment. Fracture zones occur at 1,028', 1,041', 1,052', 1,084', and 1,108'.

Unfractured rock is encountered to 1,180' where one minor fracture zone occurs, followed by unfractured rock to 1,259'. Tight hole of less than one inch diameter increase is maintained. Between 1,259' and 1,281', 3 fractures occur at 1,259', 1,261', and 1,271' causing fluctuation of the caliper log, but retaining less than one inch noise diameter increase.

Between 1,281' and T.D. of 1,345', no correlations were made though the caliper log showed hole diameter variations. A minor fracture zone is indicated at 1,338' with as many as five fractures indicated in the zone. Core shows 10 fractures in the interval 1,325'-1,339', with 4 fractures present between 1,337' and 1,339'. Considerable drill mud, control fiber, etc. was added at this interval.

The average bulk density for the granite of PM-1 is 2.80 gm./cc. The temperature log shows 1°F/100' depth from 100'-1, 100', or is 1.2°F/100' from 300'-1,300', due to minor breaks in scale at 1,100' and 1,253'. An average velocity for the PM-1 granite is approximately 19,000 ft./sec., omitting the increased travel time in areas of fracture.

Correlating the geophysical evidence with the geologic log obtained from sludge samples and five core intervals, it is noted that the occurrence of propylitization in the drill cuttings corresponds in most cases to the fracture intervals indicated by geophysical methods. The core interval from 996'-997' shows 2 tight fractures in otherwise dense, solid granite; these fractures are not indicated on the geophysical logs. It is also noted that from 600'-1,050' the fluctuation of the maximum grain size of the sludge samples is an approximation of the image of the hole diameter as recorded by the caliper log. Below 300' depth some correlation is obtained between intervals of less drill time per foot, and fractured intervals. Tight hole conditions are attained between 700'-800' depth. Pyrite was encountered in PM-1, at 430', 730', 900', and 1,170'.

PM-2 (See Plate 10 and Figure 5)

Location: N. 1,621,842.43 - E. 558,120.94

(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: vertical

Collar Elevation: 5,317.55'

Total Depth: 1,295' G.L., 1,305' K.B.

Date Begun: 3/27/63

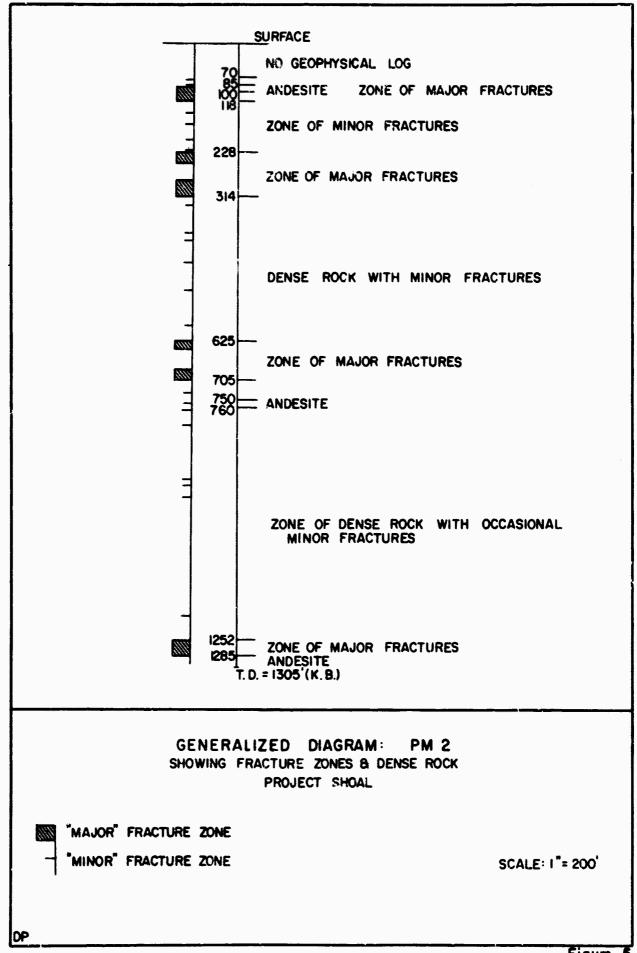
Drilling Rate: 6.61 min./ft. (Actual Drill Time)

6.86 min./ft. (Drill Time plus reaming core

intervals)

Geophysical logs of PM-2 indicate six major fracture zones and nineteem minor fracture zones, with the majority of both above 800' depth.

Logging began at 70'-80' with a minor fracture zone indicated at 72'. Geologic logging shows an andesite dike from 85'-100'; this interval is reflected by higher resistivity and density. The caliper log also reflects the interval of andesite by lesser hole diameter.



The Past

The first zone of major fracturing extends from 96'-115' with an indication of as many as six fractures. This major zone is followed by four minor fracture zones at 143', 168', 200', and 226'. The resistivity curve of the microlaterlog suggests more fractures in this interval than do the other geophysical logs.

A second major fracture zone occurs at 228'-245', with three fractures indicated. The density curve goes off scale (minimum) in this interval.

A third major zone of fracture occupies the interval 285'-314', with as many as five fractures indicated.

Below 314' the rock tends to become more solid, to a depth of 625'. It is cut by six minor fracture zones at 338', 394', 410', 457', 515', and 592'. The microlaterlog again indicates additional fractures in this interval, but is not confirmed by the remaining geophysical logs. Core from 483'-485' shows one fracture not confirmed by geophysical logs, though there is some indication of a fracture at this depth on both sonic and electric logs.

Two major fracture zones occur at 625'-640' and 686'-705'. The caliper log shows increased borehole diameter in each interval. Three to four fractures are indicated in each zone. At 705' the rock becomes more dense and solid with tight hole conditions of less than one inch diameter increase over bit size, except in zones of minor fracture which occur at 733', 755', 765', 800', 912', 925', and 950'. The geologic log records andesite in the interval 750'-760', this correlates with high resistivity and density. Core from 761'-722' shows ten fractures which would be represented by the minor fracture zone at 765'.

From 950'-1,200' the rock appears to be solid. The caliper log shows an even closer approach of hole size to bit size. At 1,200' a minor fracture zone occurs, followed by dense rock to 1,252', where a major fracture zone is represented, to 1,285'. There are indications of as many as seven fractures in this zone.

From 1,285'-1,305' (T.D.) the rock is andesite with core analysis showing 39 fractures in this interval, though most of them are tight.

The average density of PM-2 granite is 2.78 gm./cc. An average velocity of 16,700 ft./sec. is indicated for the unfractured granite. Tight hole conditions begin at 710' and are maintained to the total depth, with minor fluctuations of diameter at fracture zones.

Pyrite was first observed in the cuttings at 585' and remained fairly constant for the remainder of depth of the hole. Propylitization is a fair to poor indication of fracturing in PM-2, being absent in some intervals where logs indicate fractures, and present in other intervals where no fractures are indicated. In general, drill time per foot was less in zones of fracture; it is notably higher rear andesite contacts. Grain size of drill cuttings showed no noticeable correlation with fracturing in PM-2.

PM-3 (See Plate 11 and Figure 6)

Location: N. 1,619,192.76, E. 559,336.33

(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: vertical

Collar Elevation: 5,120.10'

Total Depth: 1,097' G.L., 1,107' K.B.

Date Begun: 4/12/63
Date Completed: 4/25/63

Drilling Rate: 6.56 min./ft. (Actual Drill Time)

6.60 min./ft. (D)

(Drill Time plus reaming of core

intervals)

Correlation of geophysical logs for PM-3 shows five major and 25 minor fracture zones. The majority of fracturing occurs above 750' depth.

Geophysical logging began at approximately 50' depth, with the interval to 312' occupied by 9 minor fracture zones at depths of 63', 75', 110', 118', 141', 179', 209', 219', and 261'. The caliper log shows +16" hole diameter (12 and 1/4" bit) to 130', and again at 220'-235'.

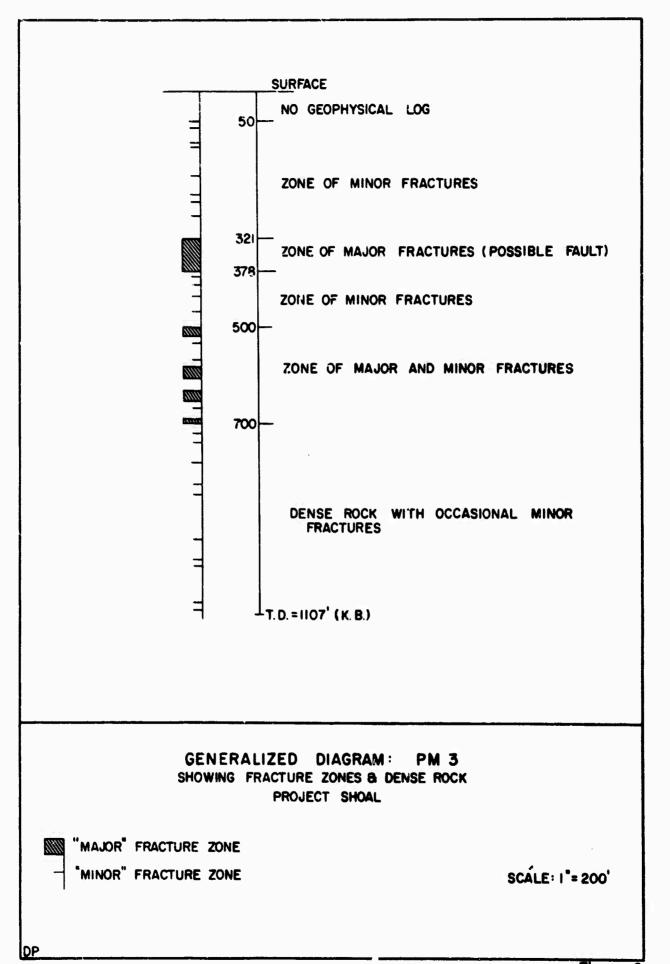
The first major fracture zone occurs at 312'-378', with indications of 10 or more individual fractures. This major zone corresponds approximately with the projected dip of the fault exposed at the surface northwest of the hole. The caliper log shows +16" hole diameter from 315'-372'; with the density log off scale (minimum); the sonic log is off scale (maximum); resistivity is low; and the radioactivity log shows the lowest neutron count for the entire log.

Four minor fracture zones are present at 392', 409', 431', and 465'; followed by a second major fracture at 500'-511', in which four individual fractures are indicated. The density curve goes off scale (minimum) in this major fracture interval.

An interval of denser rock is cut by two minor fracture zones at 530' and 565'. Core taken at 550'-562' contains 21 fractures, most of which are tight, displaying seven major dip angles. The microlaterlog gives indication of more fractures than are evidenced on the other types of logs for the entire depth of the hole.

A third major zone of fracture occurs at 582'-603' with evidence of four fractures in the zone. Resistivity is very low, as are neutron counts. The density curve goes off scale (minimum) twice in this interval, and the caliper curve shows +16" hole diameter with an eleven-inch bit size. This major zone is followed by a fourth, at 632'-650', with four fractures indicated. The resistivity is low and the caliper log shows hole enlargement.

One minor fracture at 670' separates the fourth major zone from the fifth, at 694'-700'. Three fractures are indicated in the fifth zone, with logs recording low density and large hole diameter.



Minor fracture zones are present at 720' and 740'. At approximately 760' tight hole conditions reoccur, and are maintained to the bottom of the hole. The remaining depth of hole contains minor fractures at 782', 828', 850', 946', 984', 1,077', 1,091'. Core at 1,085'-1,107' displays 25 fractures at seven major angles of dip. The majority of these fractures are tight.

Anomalous high gamma readings are present at 200' depth, which may be due to a natural concentration of more highly radioactive minerals at this position. Low gamma readings are encountered in the first major zone of fracture and continue to remain low throughout the drill depth.

An average density of the PM-3 granite is 2.75 gm./cc. An average velocity of approximately 18,000 ft./sec. is indicated for the PM-3 granite, excluding abnormal velocities in fractured intervals.

Analysis of the geologic log shows pyrite occurrence at 320'-325', 550'-555', and is fairly persistent below 700' depth. Propylitization is a fair indication of fracturing, but persists from 600'-1,000' through intervals with little or no apparent fracturing. This may be due to sluffing and wash out from other highly fractured intervals. Drill time per foot is generally less in areas of fracturing. Maximum sludge grain size is not indicative of fracturing, however maximum size is attained in the unlogged upper 70' of hole, and the interval 550'-700', containing three major zones of fracture.

PM-8(See Plate 8 and Figures 7a, b, c.)

Location: N. 1,619,967.78 - E. 557,532.73

(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: vertical

Collar Elevation: 5,237.81

Total Depth: 930' K.B. Date Begun: 4/26/63

Date Completed: 5/6/63

Drilling Rate: 10.68 min./ft. (Actual Drill Time)

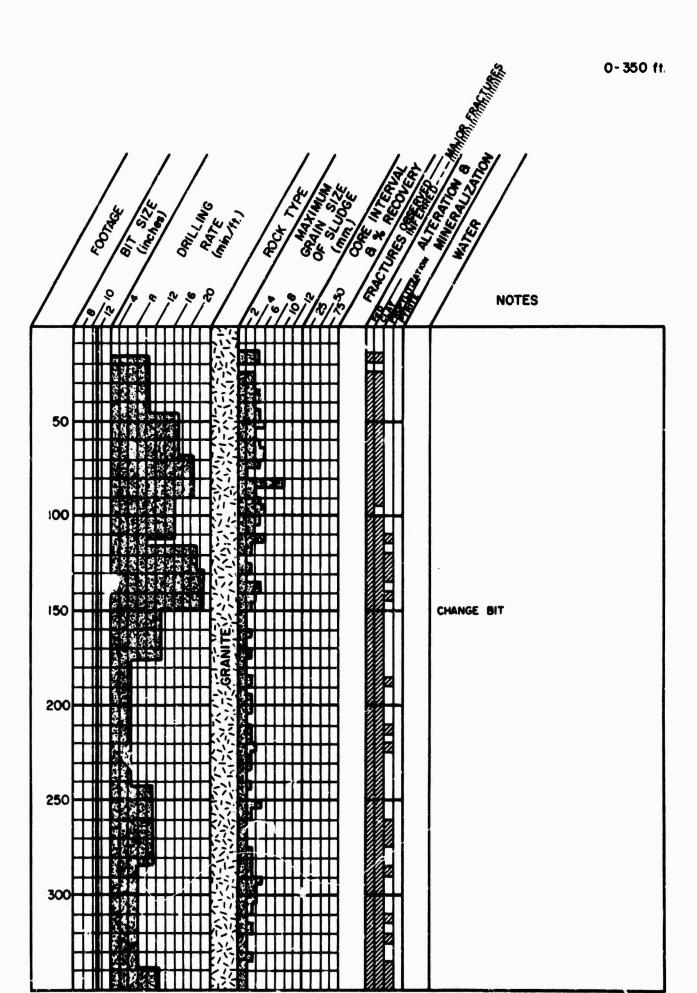
10.85 min./ft. (

(Drill Time plus reaming of core

intervals)

Since geophysical logs were not made of PM-8, no absolute correlation can be made. Due to its proximity to ECH-D, an attempt was made to correlate PM-8 with the geophysical logs of ECH-D.

Analysis of the ECH-D hole logs showed five major and eleven minor fracture zones in the upper 920'. Correlation of these zones with the geologic log prepared from sludge samples of PM-8 gave no reliable correlation with drilling rate or sludge grain size. The occurrence of propylitic alteration in the sludge samples served as a good indication of fracture zones.



Geologic Log of Drill Hole PM 8

Figure 7a

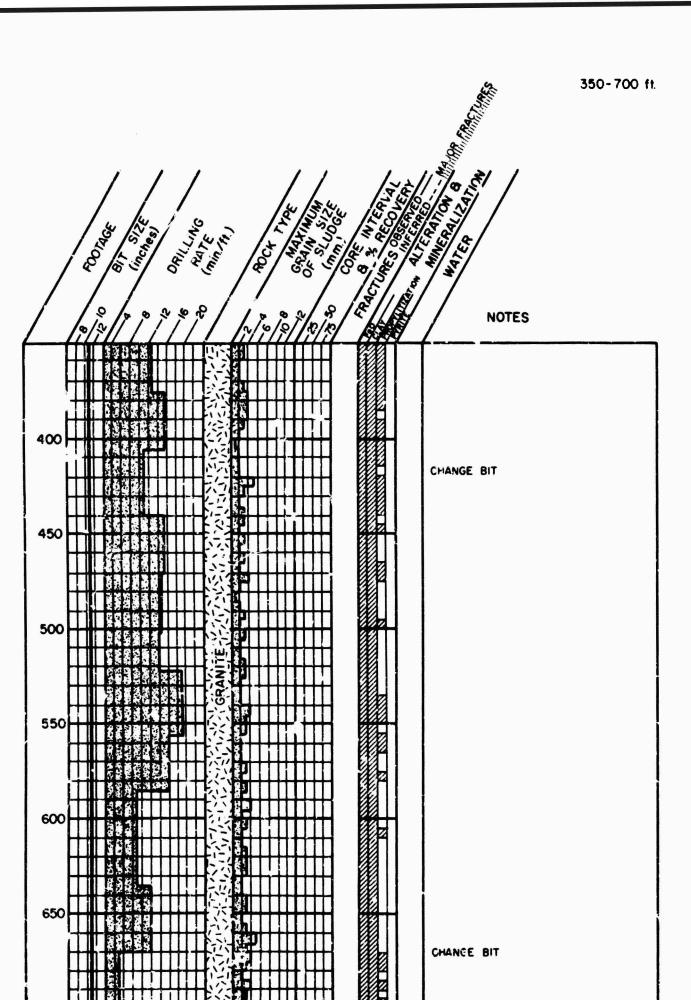
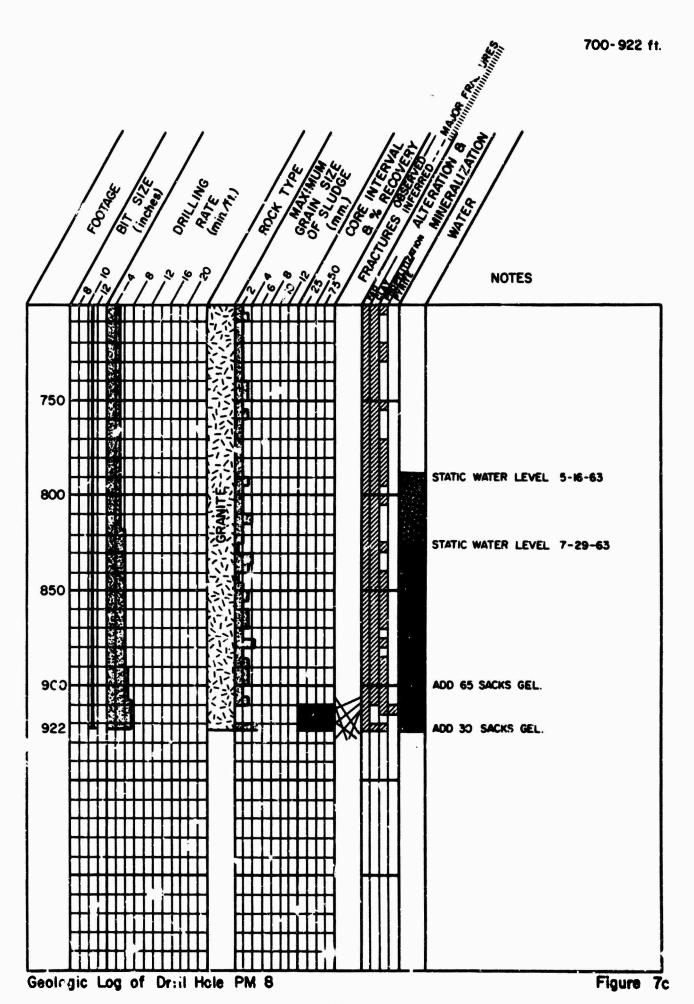


Figure 7b

Geologic Log of Drill Hole PM 8



The second secon

USBM #1 (See Plate 12 and Figure 8)

Location: N. 1,619,992.41 - E. 557,949.92

(U. S. Coast & Geodetic Survey Coordinates)

Sand Springs Range

Churchill County, Nevada

Inclination: vertical

Collar Elevation: 5,201.41'

Total Depth: 1,485.88' G.L., 1,496' K.B.

Date Begun: 6/22/63
Date Completed: 7/8/63

Drilling Rate: 6.33 min./ft. (Actual Drill Time - no core intervals)

Geophysical logging began at approximately 100' depth. C. Lockhart, Brinkerhoff representative, reported a gouge zone from 70'-110' during drilling operations. Some evidence is obtained from the caliper and sonic logs which tends to substantiate this interval as a fracture zone. Correlation of well logs show an additional 6 major and 27 minor fracture zones. The Welex Frac-Finder and Microseismogram logs are very good fracture indicators and correlate well with the standard well logs.

Minor fracture zones are encountered at 115' and 127'. The first major fracture zone indicated on geophysical logs occurs in the 138'-225' interval. There are indications of eleven fractures within this zone. The caliper log is inaccurate in this interval, as the caliper was jammed with cuttings. Sonic travel time curves go off scale (maximum) repeatedly in this interval.

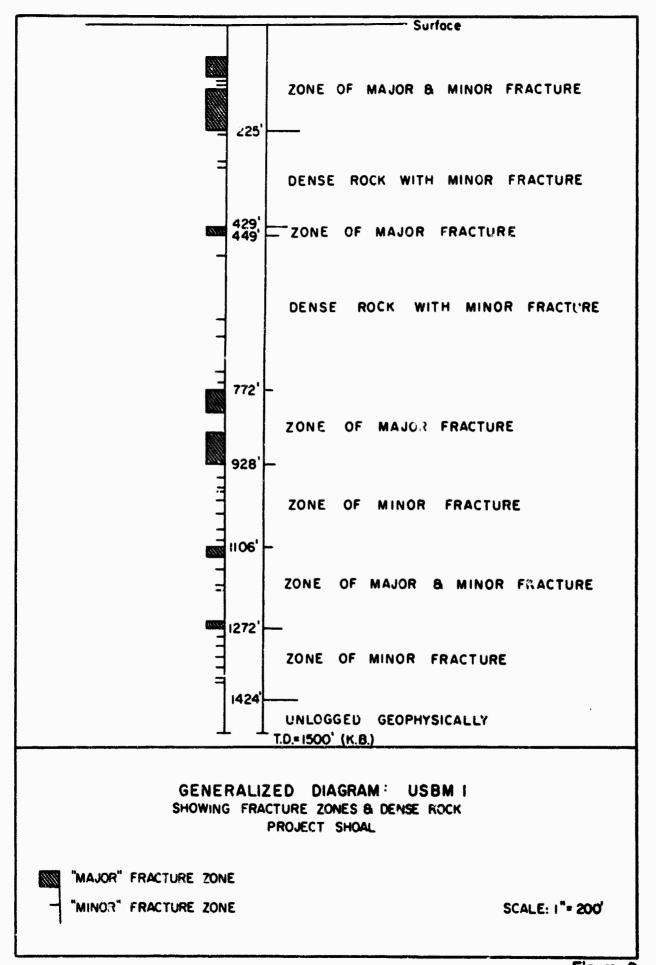
Minor fractures occur at 235', 290', and 303', followed by a second major fracture zone at 429'-449'. Four fractures are indicated in this zone.

The granite tends to become more dense below 450', and at 700' approaches "tight hole" conditions of less than one inch diameter increase ever bit size. The interval from 450'-730' is broken by three minor fracture zones, at 490', 624', and 660'. Two minor fracture zones at 737', and 758' are followed by the third major fracture zone, from 772'-820'. Seven fractures are indicated. The caliper log records +3" diameter increase.

The rock is dense and returns to less than 1 inch diameter increase until the fourth major fracture zone at 863'-928' is encountered; as high as nine fractures are indicated, with +5" diameter increase recorded in the interval. The velocity log goes off scale (maximum) in this interval, which also displays the lowest neutron count for the entire log.

From 928'-1,100' the rock is more dense, and cut by minor fracture zones at 958', 976', 985', 1,003', 1,034', 1,070', and 1,091'. The fifth major fracture zone lies in the 1,106'-1,125' interval, with four fractures indicated within the zone.

Minor fracture zones occur at 1,151', 1,186', 1,192', 1,196'. The fasc major zone occurs at 1,260'-1,272'. The velocity log goes off scale (maximum) in this interval.



Six minor fracture zones occur below 1,272', at 1,295', 1,314', 1,339', 1,359', 1,380', and 1,388'. Tight hole conditions are maintained in this interval.

This hole differs from the other instrument holes, in that most of the fracturing occurs below 750' depth. In the other instrument holes, most of the fracturing occurs above 750'-800' depth.

There are indications, on individual logs, of more fractures than can be correlated with the other logs. A velocity of 18,200'/sec. is recorded for the unfractured granite. High gamma counts are recorded at 853', 900', 1,080' and 1,398'.

There is no apparent correlation between the drilling rate, or maximum sludge grain size, and the fracture intervals of the drill hole. Pyrite is first encountered at 885'; again at 905' and remains for the depth of hole. Propylitization is a fair indication of fracturing, though it is present in zones with no recorded fracturing.

SUMMARY AND CONCLUSIONS

Although geophysical logs were primarily designed for analysis of sedimentary formation, they may also be used as a space semi-quantitative tool for the location of fractures and the determination of fracture density in areas of crystalline igneous rocks. Depending on the sensitivity of the individual logging method, some types of logs indicate more fractures than do other logs.

Areas of fracture are indicated by low resistivity, low neutron counts, low density, increased hole diameter, and increased transit time. The gamma ray log shows only the natural radio activity of the granite, and does not reflect fracturing. The spontaneous potential curve tends to be somewhat featureless due to an essentially homogeneous rock type. The temperature curve shows a geothermal gradient of approximately 1°/100' depth (F°).

Of the standard well logs, the microlaterlog (with caliper), neutron log, density log, and sonic log are the most indicative of fracturing. The Welex Frac-Finder and Microseismogram logs are also very good fracture indicators.

The microlaterlog gives more resolution of closely spaced fractures than any of the other resistivity measuring logs, due to its closely spaced electrodes. This log gives a semiquantitative approach to the determination of fracture density within a fracture zone, and is especially valuable when both linear and compressed scales are available. The microlaterlog often indicates fracturing which cannot be detected by other types of logs.

Core analysis showed many tight fractures which do not give characteristic evidence on the geophysical logs. Some intervals also contained more fractures than were indicated on the logs.

Unless drill holes are cased, the sludge sample for any particular depth may be contaminated by the entire hole above that depth. Except for alteration and mineralization study, and lithologic changes, it is of little value in an uncased hole. On the basis of propylitization in the sludge samples, one would expect to find more fractures than were logged, which may be due, in part, to salting of the sample by the uncased hole.

The majority of "open" (or "log-detected") fractures occur at depths of less than 800 feet, with PM-1 and USBM #1 as partial exceptions. Tight hole conditions are generally assumed at depth below 700'-800' in all holes. The stress-strain hysteresis curves obtained from ECH-D core analysis shows a tightening of fractures below approximately 800' depth, assuming 1 p.s.i. per foot of depth, which correlates with the geophysical data. This approximate depth also corresponds approximately with the static water levels measured in the holes.

Sulfide mineralization (pyrite) occurs at various depths in the holes; 430' in PM-1, 585' in PM-2, 320' in PM-3, 920' in PM-8, and 875' in USBM #1.

The average density of the granite encountered in the instrument holes is 2.77 gm/cc, as determined from the geophysical logs. The average velocity for the "unfractured" granite is 18,000 ft./sec.

Average drill time for the holes was 6.54 min./ft. with the exception of PM-8 which took 10.68 min./ft. In most holes there is some correlation of decreasing drill time with areas of fracture.

It was proposed to cut and remove the cables post-shot from PM Nos. 1, 2, and 3. Because the installed instruments survived in good condition, the proposal was dropped. Also, from the post-shot surface mapping and reconnaissance, it is doubtful that relogging the holes would reveal increased porosity and permeability as consequences of the shock. Our proposal for removing the cables was made thinking such might be the case.

BIBLIOGRAPHY

- Haun, J. D., Subsurface Geology in Petroleum Exploration: Golden, Colorado School of Mines, 1958.
- Holmes & Narver Inc., Interpretation of Geophysical Borehole Logs of Core Hole "D", Project Shoal: Report to A.E.C., Sept. 1962.
- Levorsen, A. I., Geology of Petroleum: San Francisco, California, W. H. Freeman, 1954.
- Pirson, S. J., Handbook of Well Log Analysis: Englewood Cliffs, New Jersey, Prentice Hall, Inc., 1963.
- Schlumberger Well Surveying Corp., Schlumberger Well Logging Document No. 8: 1958.
- University of Nevada, Geological, Geophysical, and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada: Sept. 1962.
- Welex, Welex Frac-Finder log and Micro-Seismogress Log: Reference material supplied on request, Houston, Texas: July 23, 1963.

Temperature Measurements by R. C. Horton

OBJECTIVES

Pre-shot temperature measurements were made at selected stations in underground workings and drill holes to determine the thermal gradient and conductivity of a granite mass in situ.

Post-shot measurements are proposed for comparative purposes.

EQUIPMENT AND INSTRUMENTATION

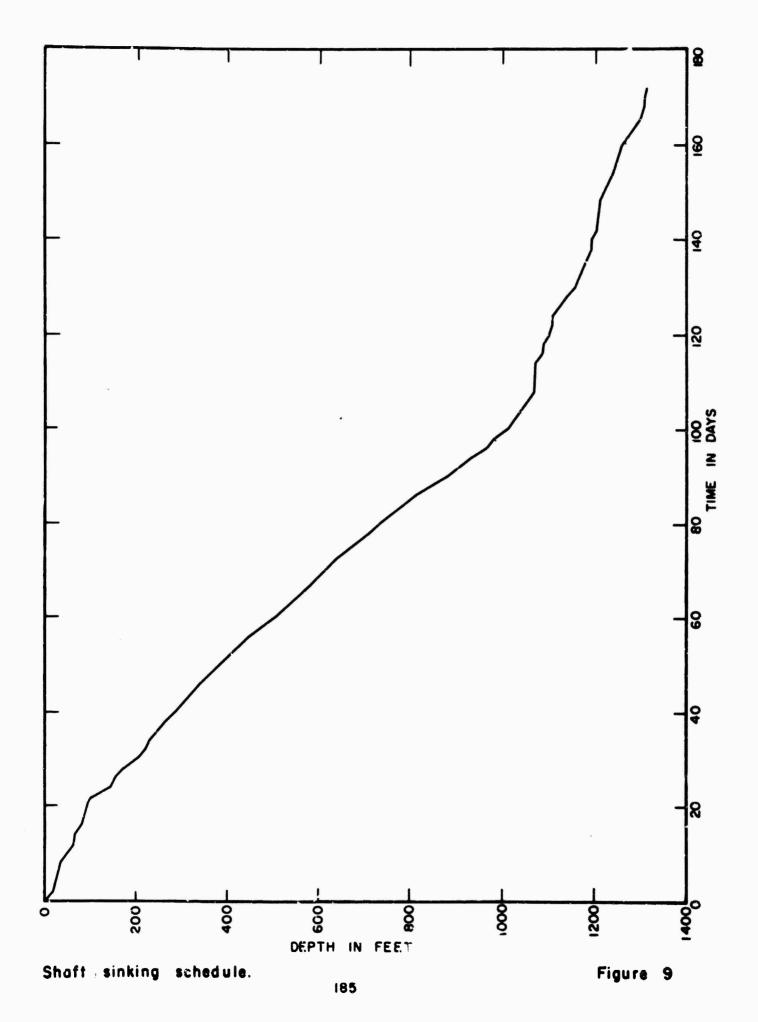
Temperature measurements were made using copper-constantan thermocouples and a Minneapolis-Honeywell Reg. Co. Rubicon model 2745 potentioneter with a spotlight galvanometer. The potentiometer could be read to 0.005 millivolts and readings estimated to 0.001 millivolts. The thermocouples were constructed of 24 guage plastic coated copper and constantan wire. All thermocouples were obtained from a single copper-constantanpaired length of thermocouple wire. The thermocouples were attached to one and one-half inch diameter styrofoam rods for placement in the drill holes. Small strips of aluminum foil were wrapped around the ends of the rods and the thermocouples to insure good thermal contact with the rock. When emplaced the styrofoam rods filled the drill holes.

The cold junction was imbedded in an aluminum foil wrapped three inch diameter rod of styrofoam containing a mercury thermometer that could be read to 0.1 deg. Celsius and estimated to 0.05 deg. Celsius. The cold junction of the thermocouple was in contact with the bulb of the mercury thermometer. An ice bath was not used for controlling the temperature of the cold junction because of the difficulty in handling and transporting an ice bath in the underground areas.

OPERATIONAL PROCEDURES

Surface, air, and water temperatures were measured with a thermocouple identical to those used in the drill holes. Surface temperatures were measured on dry areas of the walls to eliminate temperature variations caused by evaporation.

The thermocouples were emplaced on September 9, 1963, six days after completion of mining. Readings were made on October 1 and October 4. Additional readings were desirable but could not be taken because of construction activity in the shaft and drifts. Figures 9 and 10 indicate the progress of excavation in the shaft and drifts. Using day 0 as the start of mining; the shaft was completed on day 172, the west drift completed on day 252, and the east drift on day 254. Thermocouples were installed on day 266, and readings made on day 288 and day 291. D day was day 313. Figure 11 shows the location of the thermocouples in the shaft and drift.



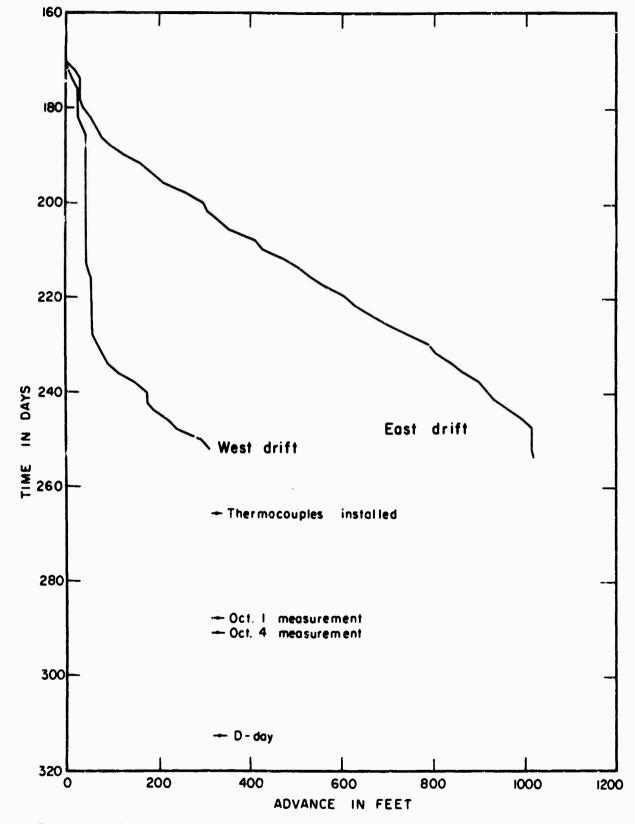


Figure IO. Drift advance schedule.

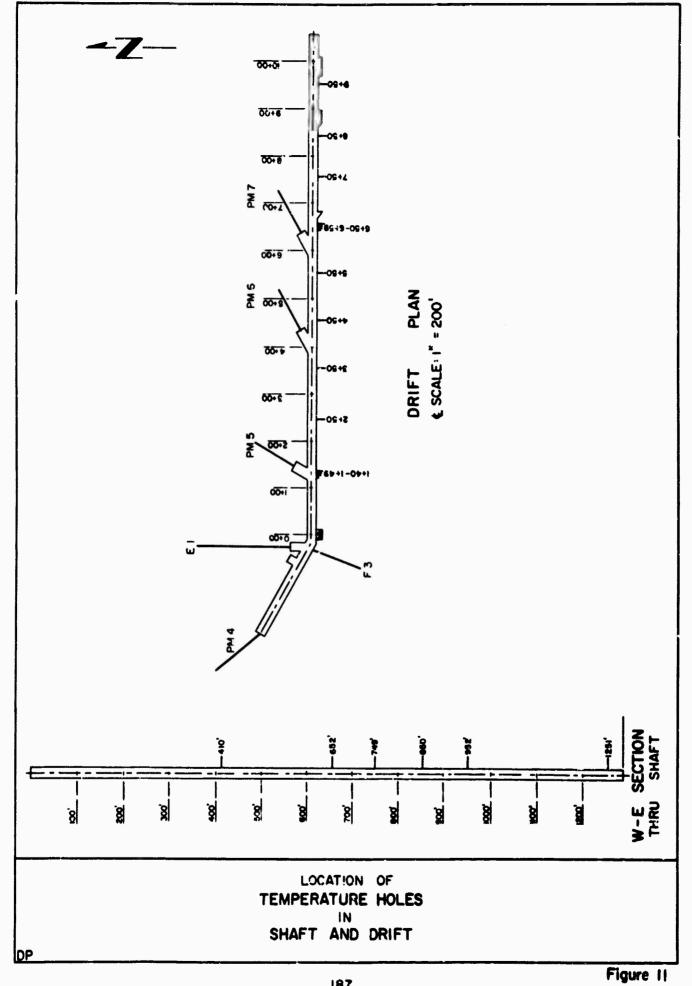


Figure 12 is an illustration of the temperature readings obtained in the drifts on October 1 and October 4. Surface and air temperature measurements were not taken on October 1. Figure 13 is an illustration of the temperature readings obtained in the shaft and in temperature logs of drill hole ECH-D. Table 3 lists the actual temperatures measured at various localities.

Weather information is not presently available so comments cannot be made concerning the long term effects of ventilation on the temperatures measured underground. The general increase in temperature measured in the drill holes during the period October 1 to October 4 indicates that the wall rocks are gaining heat from the air as there is a decrease in temperature from the air to the rock surface and from the rock surface to the 2 feet deep drill holes.

The temperatures of the 4 feet, 6 feet, and 8 feet deep drill holes do not indicate a consistent direction of heat flow. On October 1 the 6 feet and 8 feet deep holes were all at the same temperature but, at stations 1+ 40-50 were cooler than the 2 feet and 4 feet deep holes. On October 4 the 6 feet and 8 feet deep holes were warmer than the 2 feet deep holes. Water temperatures measured at the shaft and at a long horizontal drill hole near station 10+10 were warmer than any of the surface or drill holes temperatures measured in the east drift. The rock in the vicinity of the east drift may be receiving heat from circulating air and from ground water. If water is adding heat then this water is rising from a higher temperature zone below the drift elevation. A dual heat source would account for the unusual thermal gradients in the wall rock.

The temperature at the face of the east drift, as computed from the temperature log of ECH-D, should be 20.27 Celsius. The rock, surface, and air temperatures trend toward this temperature as shown on Figure 12.

No temperature holes were drilled in the west drift. There is a remarkable correlation between the rock surface temperatures and the air temperatures in the west drift. As the air temperatures are higher than the rock surface temperatures, the rock surface is gaining heat from the air.

During the time the temperature measurements were made on October 4 there was little activity in the west drift and the ventilation system was not in operation. Three men were hauling sacks of vermiculite from the shaft station to a small alcove near station 6+00 in the east drift. This activity probably accounts for the air temperature rise in the vicinity of station 6+00. The sacks of vermiculite had been stacked at the collar of the shaft, exposed to direct sunlight, and were warmer than the air temperature in the east drift.

The temperatures measured on October 1 in drill holes in the shaft, are obviously out of balance, when compared to the temperature log for ECH-D, and do not represent the thermal gradient. For this reason additional

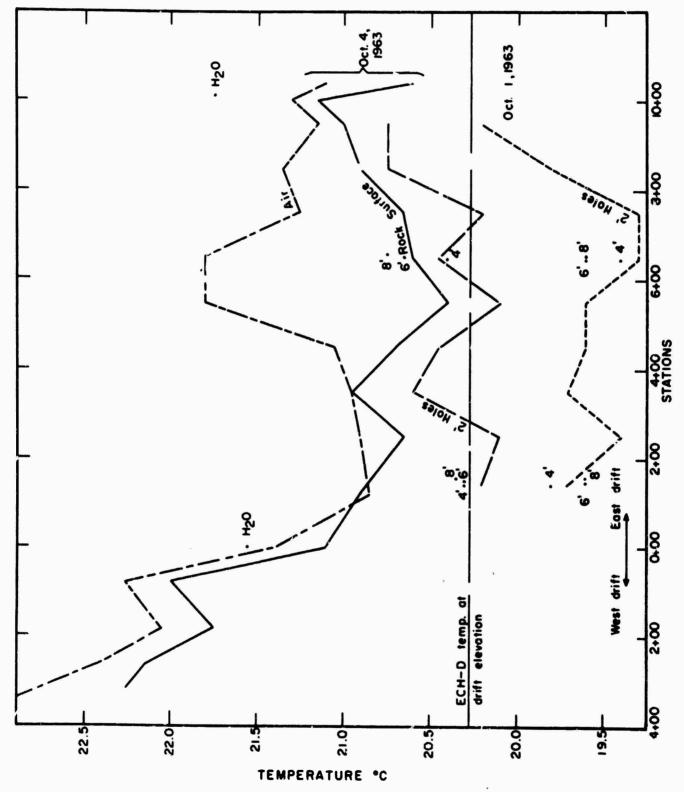


Figure 12. Drift temperatures.

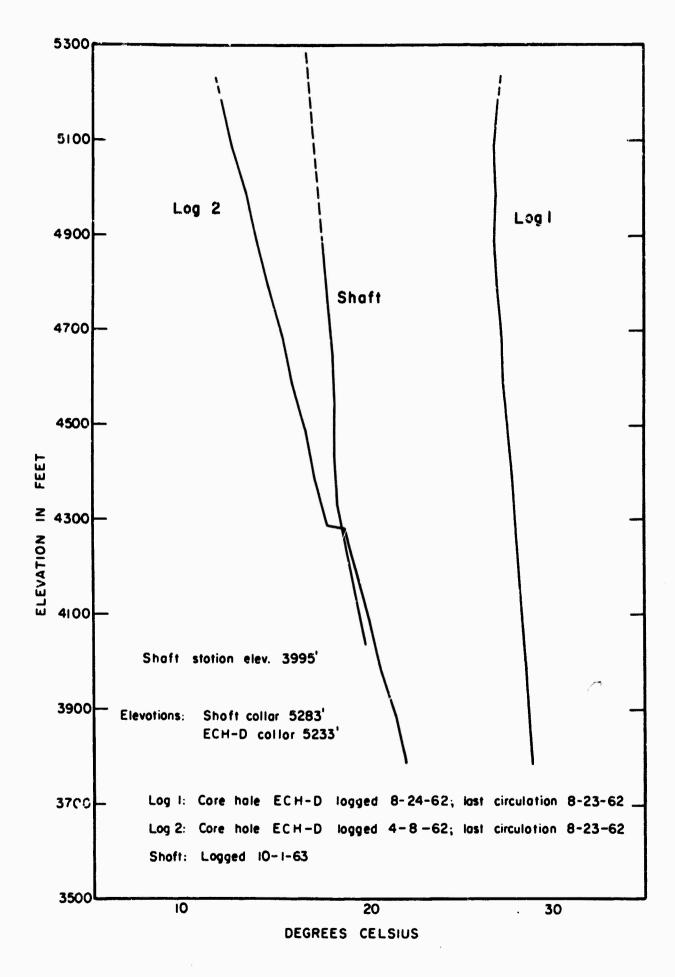


Figure 13. Temperature logs, core hole ECH-D and shaft.

TABLE 3
Temperature Measurements in Shaft and Drifts

		Oct. 4, °C			Oct. 1	Depth	1
Remarks	Water	Air	Surface	Hole	°C/hole	of Hole	Station
	_						Shaft
					17.6	2'	410'
					18.2	2'	6521
					18.3	2'	7491
					18.4	2'	8521
					18.7	2'	952'
					19.9	2'	1251'
							East
					!		Drift
		20.90	20.90	20.20	19.70	2'	1+40
		20170	20170	20.30	19.80	4'	1+43
				20.30	19.60	6'	1+46
				20.35	19.60	8'	1+49
		20.90	20.65	20.10	19.40	2'	2+50
		20.95	20.95	20.60	19.70	2'	3+50
		21.05	20.70	20.45	19.60	2'	4:50
		21.80	20.40	20.10	19.60	2'	5+50
		21.80	20.60	20.45	19.30	2'	6+50
				20.40	19.40	4'	6+53
				20.65	19.60	6'	6+56
				20.75	19.60	8'	6+59
		21.25	20.65	20.20	19.30	2'	7+50
		21.35	20.90	20.75	19.80	2'	8+50
		21.15	21.02	20.75	20.20	2'	9+50
		21.30	21.15			I	10+00
		21.16	20.60				10+40
Water flowing	21.75						10+10
from diamond do 11 hole							
·							West
							Drift
01-6-0	21 55	21 /0	21 10				0+00
Shaft Station	21.55	21.40	21.10				0+80
		22.25	22.00 21.75		İ		1+80
		22.10	22.15			1	2+65
		22.40	22.13				At
Water 61	25 00	22.80	22.25				Face
Water flowing from PM hole	25.00	22.00	22.23				race

measurements were not made in the shaft on October 4. Figure 13 illustrates the temperatures measured in the shaft and the two temperature logs of core hole ECH-D. Log 1 was recorded one day after drilling was completed. Log 2 was recorded seven and one-half months later. The linear nature of log 2 and the temperature step recorded at the water level indicate that it is a correct recording of the temperature gradient. The temperature gradients as scaled from the original of log 2 are as follows:

Depth	Interval		val Temperature Increase		ncrease	Remarks
50'	to	150'	0.67 de	eg.	С	temperature at 50', 12.1 deg. C
150'	to	250'	0.67 d	eg.	С	
250'	to	350'	0.56 d	eg.	С	
350'	to	450'	0.67 d	eg.	С	
450'	to	550'	0.78 d	eg.	С	
550'	to	650'	0.44 d	eg.	С	
650'	to	750 '	0.83 d	eg.	C	
750 '	to	850'	0.44 d	eg.	С	
850'	to	950'	0.70 d	eg.	C	temperature at 950', 17.9 deg. C
950'	to	1050'	0.72 d	eg.	C	water level at 955' - temperature
1050'	to	1150'	0.67 d	ėg.	С	projected to 950', 18.7 deg. C
1150'	to	1250'	0.62 d	eg.	C	
1250'	to	1350'	0.78 d	eg.	C	
1350'	to	1450'	0.62 d	eg.	C	
1450'						temperature at 1450', 22.1 deg. C

It is hoped that re-entry will be possible, so that post-shot temperatures can be compared with the above results.

Exposure of Minerals and Other Substances to High-Pressure Shock-Waves by John H. Schilling

OBJECTIVES

The purpose of this experiment is to determine what shock-induced changes took place in a variety of minerals, rocks, chemicals, and other substances exposed to shock pressures of 1 to over 500 kilobars generated by the Shoal nuclear explosion. In addition to supplying extremely high pressures, the shock waves generated by an underground nuclear explosion have a pulse that lasts several times longer than those from any other source, and are unique in having negligible curvature over areas of a square foot.

To accomplish the desired objective, a large number of samples were placed in several types of canisters and emplaced in holes along the Shoal drift at distances ranging from 30 to 320 feet from the detonation point. One set of canisters containing samples were prepared by the Nevada Bureau of Mines; others were submitted by John Wiese of Richfield Oil Corporation and Frank Dachille of the Materials Research Laboratory, Pennsylvania State University. The Nevada Bureau of Mines canisters also were calibrated using temperature-indicating paints so that the maximum temperature to which each canister was exposed can be determined to within 100° C over a range of 110 to 1350° C.

The lawrence Radiation Laboratory emplaced different types of sample canisters along the Shoal drift. As their samples in part duplicate those of our program, a comparison can be made of the changes that take place. The variety of canisters employed should be helpful in determining the most suitable canister design for future studies; this is a secondary objective of the experiment.

DESCRIPTION OF SAMPLES AND CANISTERS

The samples were chosen: (1) to provide as great a variety of minerals and rocks as possible; (2) to provide pressure indices; (3) to learn more about specific substances or groups of substances; and (4) to study specific reactions.

All nine of the Nevada Bureau of Mines canisters contain the same 18 rocks and minerals. Twelve varieties of feldspar were included; these were furnished and will be studied by H. Bonham of the Nevada Bureau of Mines as part of the feldspar research being carried on at the Mackay School of Mines --- no specific reactions have been predicted. Samples of granite from 995-feet in drill hole ECH-D were included as a comparison with the granite in the Shoal tunnel walls; this should provide data on how containment in canisters altered the effects of the shock wave. Biotite flakes, concentrated from a quartz monzonite intrusive, were included to see what effect shock pressures have on releasing argon held in the crystal lattice; the amount of argon in biotite is used in potassium-argon isotopic age determinations to establish the age

of igneous rocks --- possibly earthquakes could release argon which would result in inaccurate age dating. Samples of gypsum, quartz, basalt, and limestone also were included.

The Richfield Oil canisters each contain a single sample of either oil n-octane, n-butylbenzene, and octene-2, to help determine what might happen to hydrocarbons such as those in the Athabasca, Canada, oil sands, if a nuclear device were detonated in or near these sands. Type A canisters 1 to 8 and 41 to 43 and Type B canisters 1 to 8 and 12 contain oil sand; Type A canisters 21 to 28 contain extracted oil; Type A canisters 11 to 16 contain n-octane; Type A canisters 31-33 contain n-butylbenzene; and Type A canisters 51 and 52 contain octane-2.

The Penn State canisters 600 and 150 contain granite, sandstone, coal, common rock-forming minerals (anatase, andalusite, kyanite, sillimanite, albite, anorthite, apatite, biotite, aragonite, epidote, garnet, graphite, hornblende, microcline, magnetite, serpentine, fosterite, olivine, tourmaline, rutile, quartz, coesite, and zircon), and chemicals (AIN, BN, BeF₂, BAsO₄, AIPO₄, FePO₄, LibO₂, GeO₂ PbO₂, 2 FeO·SiO₂, 2 MgO·SiO₂, Mn₂SiO₄, Ni₂SiO₄, and CS₂). The 600 A canister contains quartz, coal, graphite, and CS₂; canister 25 contains granite, sandstone, quartz, coal, biotite, aragonite, microcline, and CS₂; canister 9 contains granite, sandstone, and quartz.

In order that the samples can be recovered they must be placed in containers which will protect them from loss or destruction during the nuclear detonation and later recovery operations. To do this the canister must not break, melt, decompose, etc. At the same time, the canisters should be designed: (1) to allow the shockwave to reach the samples with as little distortion and decrease in intensity as possible; (2) to shield the samples as much as possible from unwanted effects such as radiation and high temperatures; (3) to prevent unwanted interactions between samples, and between and the canister itself; (4) to make removal of the samples from the canisters relatively easy without destroying material; (5) to make fabrication relatively easy and cheap; and (6) to use materials that will not remain dangerously radioactive for long periods of time.

Obviously any design and material used represents a compromise based on the relative importance of the above, and any other special, objectives. And because so little of what actually happens to the canisters and contents presently can be predicted with any accuracy or detail, design remains an art based on little past experience. Thus a study of how well the various types of canisters performed is particularly important.

Four different types of canisters were used. The Nevada Bureau of Mines canister is shown in Figure 14. Ten one-inch-long, 15/36-inch diameter cores of each of the samples except biotite were cut from large pieces of sample material. A set of these were placed in the holes in the canister, separated by 1/2-inch-long brass spacers with a 1/4-inch capspacer at the "top" end; one set was kept for comparison, Both spacers and cores fit snugly into the holes. A given sample occupies the same

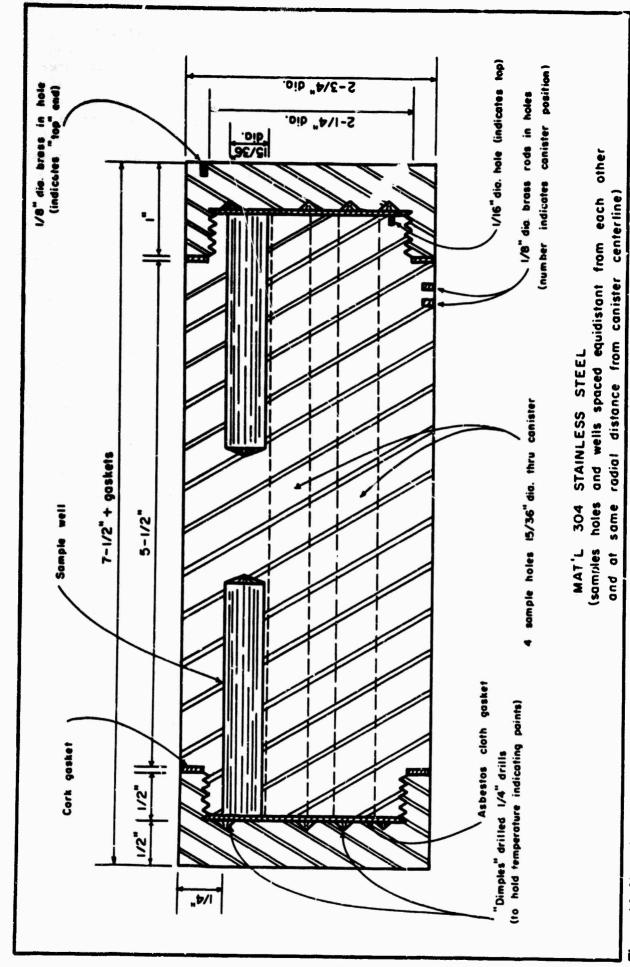


Figure 14. Nevada Bureau of Mines canister.

position and hole in every canister. The samples thus can later be removed either by pushing them out of each hole with a rod, or by cutting each canister into slices through each set of spacers. The gypsum cores were placed in the well in the "bottom" end of the canisters with an air space instead of cap-spacer. The loose biotite samples were placed in the other well and tamped and held in tight with a cap-spacer. Temperature-indicating paints that change color at 110, 140, 165, 175, 220, 290, 340, 440, 520, 560, 640, 715, 805, 900, 1000, 1100, 1200, 1250, and 1350 degrees Centigrade were placed in "dimples" drilled on the inside surfaces of the canister caps.

The two types of Richfield Oil canisters are shown in Figures 15 and 16. The oil samples were placed in an N₂ environment. The oil sands and oil sand-limestone mixtures were tamped in (to approximate in-situ packing), and were also placed in a N₂ environment. The hydrocarbons were poured in after their canisters were filled with pure silica sand. The canister plugs were then heliarc welded in place under pressure.

The Penn State canister is shown in Figure 17. Both ends were threaded, and closed by 1/2-inch thick, threaded, male steel plugs. Most of the samples were placed in individual 2 mm.-diameter gold tubing of and it lengths, then closed by carbon are welding and subjected to least to mepaction of about 20,000 psi. To simplify recove 4 or 5 of these capsules were wrapped in aluminum foil to form a tube, then isostatically pressed. In a few cases where larger amounts of the powdered material was required thin-walled, 1/4-inch diameter silver tubes were used. Sandstone, granite, coal, and single crystals were cut into one-inch blocks of suitable length and were wrapped closely in aluminum foil. All the enclose samples were grouted into the canisters with neat cement which was allowed to harden under pressure applied by the threaded plugs.

OPERATIONAL PROCEDURES

The canisters had to be emplaced at varying distances from the detonation point in order to provide the desired range of pressures of 1 to over 500 kilobars. And they had to be placed far enough into the Shoal-tunnel wall to reduce distortions of the shockwave, yet close enough to the tunnel to make recovery relatively easy.

Eight 3-inch diameter holes were drilled 4 feet horizontally into the north wall of the tunnel 5 feet above the tunnel floor. Table 4 gives the position of these holes, their designations, and which canisters were emplaced in each. Figure 18 shows their locations in the drift.

The canisters, which had been color-coded were manually grouted in place. Small quantities of magnetite sand, cement, and water were mixed to a "soft butter" consistency; a small amount was shoved into the hole; a canister was inserted in the hole and tamped until the soft grout had squeezed out around and tightly enclosed the canister; the process was repeated until all canisters were emplaced; then the rest of the hole was tamped full of grout.

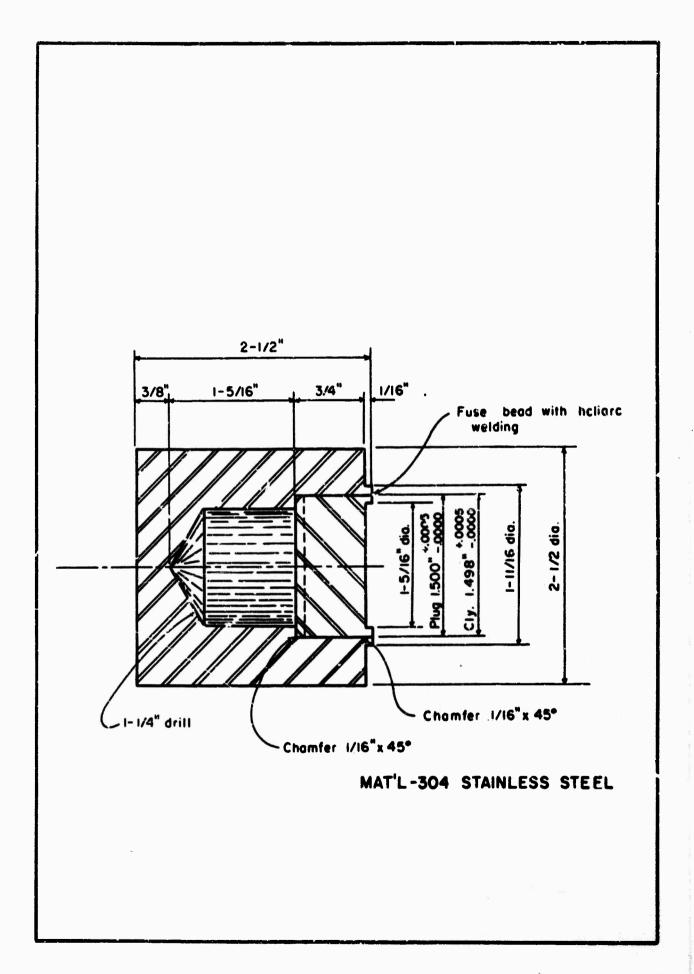


Figure 15. Richfield Oil type A conister.

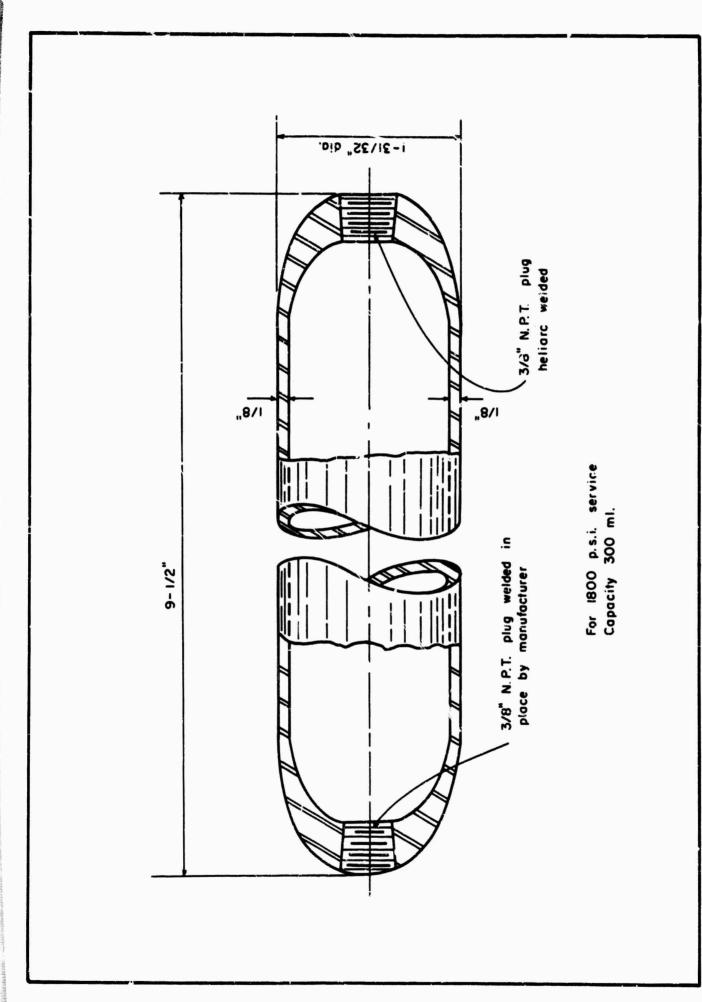


Figure 16. Richfield Oil type B (Hoke Pressure Sample Container) canister.

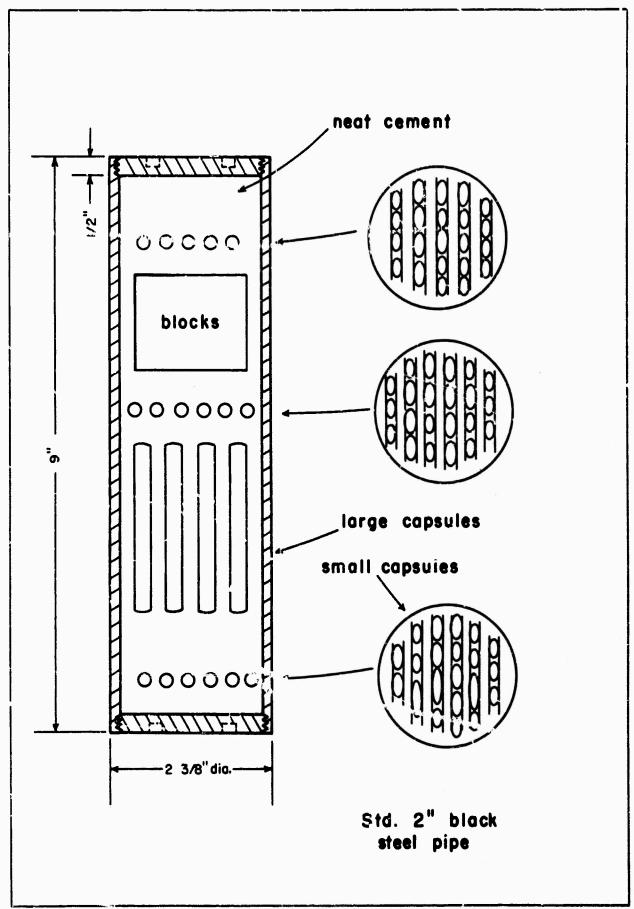
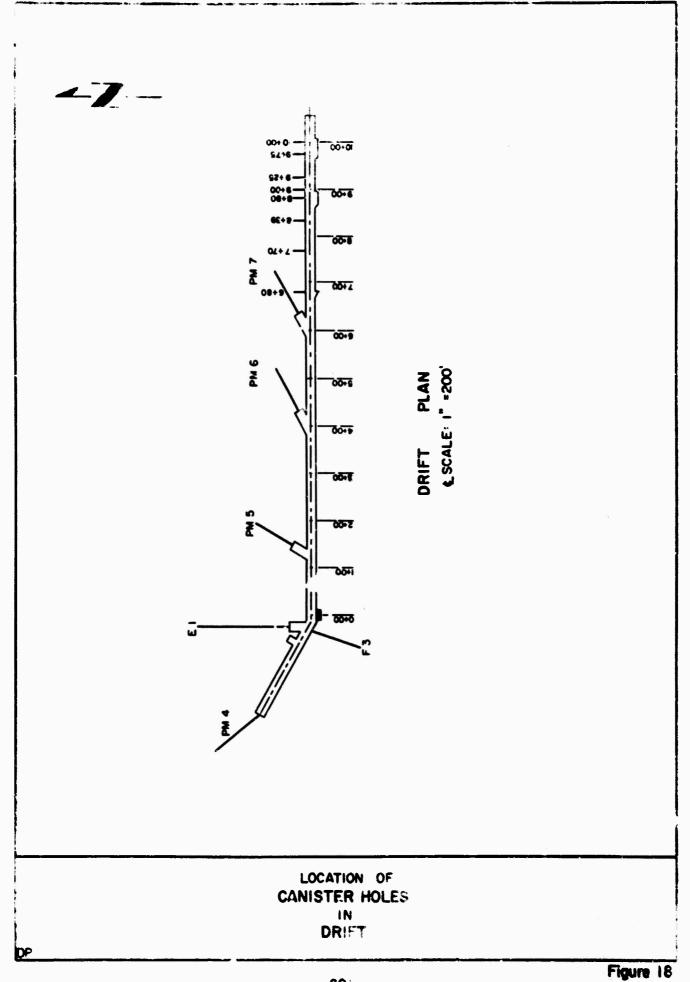


Figure 17. Penn State canister.

TABLE 4
PROJECT SHOAL
CONTENTS AND POSITIONS OF EMPLACEMENT HOLES

Hole No.	Approx. Dist. from Deton- ation Point	Dist. from Centerline Shaft	Camisters (NBM-Nevada Bureau Mines; PS-Penn State; R-Richfield Oil) enclosed
C-7	30 ft.	1000 ft.	NBM 7; PS 600 & 600A; R(Type A) 1, 21, 41; R(Type B) 1
C-1	40 ft.	975 ft.	NEM 1; PS 150 & 150A; R(Type A) 2 & 22, R(Type B) 2
C-2	80 ft.	925 ft.	NBM 2; R(Type B) 3; R(Type A) 3, 23, 43, 11; R(Type B) 12
c-3	100 ft.	900 ft.	NBM 3, PS 25, R(Type B) 4, R(Type A) 4, 24, 31, 12
C- 5	120 ft.	880 ft.	NEM 5, R(Type B) 5, R(Type A) 5, 25, 51, 13
C~6	160 ft.	839 ft.	NBM 6, PS 9, R(Type B) 6, R(Type A) 6, 26, 32, 14
C-8	240 ft.	770 ft.	NEM 8, R(Type B) 7, R(Type A) 7, 27, 52, 15
C-9	320 ft.	680 ft.	NBM 9, R(Type B) 8, R (Type A) 8, 28, 33, 16

Note: Canist is listed in order of emplacement from "bottom" to "top" of holes.



One canister (NBM-4) was placed in the center of sand plug No. 4 at an approximate distance of 105 feet from the detonation point. Heavy-duty steel bands were clamped around this canister, then bolted to a wire rope which was extended beyond the plug hulkheads. The cable was attached to facilitate recovery.

RESULTS

The canisters must be recovered before the study can be completed and results made known.

CHEMICAL INVESTIGATIONS

X Ray Spectrographic Analysis Of Major Elements For Granice From Drill Hole ECH-D by P. A. Weyler and A. Volborth

INTRODUCTION

Samples were obtained at approximately 50 foot intervals from Drill Hole ECH-D and were analyzed for silica, alumina, iron, potassium, calcium, titanium and manganese by X-ray spectrographic methods. Intensity ratios were based on the U.S.G.S. standards Granite G-l and Diabase W-l (Stevens and others, 1960) for all determinations and in addition, the standard Syenite 1^a (Nonmetallic Stds. Comm. keport, 1961) was used for alumina. Six pressed-powder pellets were made of each sample; three from iron grinding equipment and three from ceramic grinding equipment to provent introduction of unwanted impurities. Standard and relative deviation was calculated for each trio of pellets for each element.

SAMPLE LOCATIONS AND SAMPLE PREPARATION

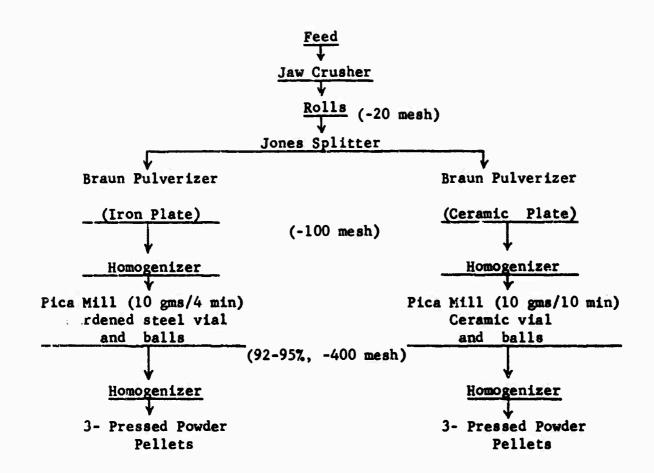
The thirty four samples analyzed are listed in Table 5 which shows the intervals at which the samples were cut. Each of these intervals was given a NMAL sample number which is used for the analytical data.

Each of the samples was washed and air dryed before crushing to remove any adhering material, and an effort was made not to contaminate the sample in any manner. The samples were crushed to 20 mesh and split. Each half of the split was then ground as shown below. By grinding the samples in different media, the type of contamination is known and the amount of contamination can be determined if desired.

The iron ground pellets were used to determine Si, Al, K, Ca, and Ti, and Fe and Mn were determined using the ceramic ground pellets.

TABLE 5
CORE SAMPLES FROM ECH-D
Sample interval measured from Collar (in feet)

NMAL No.	Interval	NMAL No.	Interval		
1	D: 308 - 308	.65 18	D: 1150.0 - 1150.65		
2	D: 349.1 - 349	.6 19	D: 1204.6 - 1205.4		
3	D: 402.3 - 403	20	D: 1250.0 - 1250.7		
4	D: 450.3 - 451	.0 21	D: 1300.35- 1300.95		
5	D: 500.09 - 500	.84 22	D: 1349.5 - 1350.1		
6	D: 549.5 - 550	.4 23	D: 1403.0 - 1403.8		
7	D: 600.1 - 600	.85 24	D: 1438.4 - 1439.1		
8	D: 651.66 - 652	.44 25	D: 1501.0 - 1501.6		
9	D: 699.4 - 700	0 26	D: 1548.3 - 1549.0		
10	D: 750.0 - 750	.8 27	D: 1653.1 - 1654.0		
11	D: 800.38 - 800	.88 28	D: 1701.3 - 1702.2		
12	D: 850.0 - 850	.8 29	D: 1751.05- 1751.85		
13	D: 892.4 - 892.	.8 30	D: 1800.5 - 1801.5		
14	D: 950.1 - 951.	.0 31	D: 1849.0 - 1850.0		
15	D: 999.3 -1000.	.0 32	D: 1899.0 - 1899.6		
16	D: 1049.45 -1050.	.0 33	D: 1951.0 - 1951.8		
17	E: 1101.0 -1101.	.55 34	D: 2001.9 - 2002.4		



EQUIPMENT AND INSTRUMENTAL CONDITIONS

The equipment used was standard Norelco X-ray units consisting of constant potential generator, Universal vacuum spectrograph and electronic circuit panel with pulse height analyzer and high speed electronics.

All the instrumental operating conditions such as voltage, crystal, 20, pulse height settings, collimation, etc. are listed in Table 6.

ANALYTICAL DATA

The procedure and techniques used in the analyses were those developed in this laboratory by A. Volborth. For a complete description of the method, the reader is referred to Nevada Bureau of Mines Report 6, Total Instrumental Analysis of Rocks, 1963.

Briefly, the method used for this report is as follows: 1) The standard Norelco sample holder fits four pellets and each pellet was counted four times in the sequence 1, 2, 3, 4, 4, 3, 2, 1, 1, 2, 3, 4, 4, 3, 2, 1 for a fixed count. The intensity ratio to G-1 was determined from the average of the four counting times. The only exception was for manganses where a fixed time (64 sec.) was used. 2) Using the average of the W-1 to G-1 ratios as the second point, a calibration curve (intensity ratio vs. % composition) was drawn assuming a straight line between the points. Due to the enhancement of alumina by silica, a special calibration curve and a correction factor is required. This is described later in the report under alumina. 3) The slope and y-intercept for each calibration curve was

TABLE 6
INSTRUMENTAL CONDITIONS

Total Counts	204,800	25,600	204,800	204,800	25,600	102,400	Fixed time - 64 sec.
Pellet Grind	P. e	Pe	Cer	P.	F.	G G	Cer
Colli- mator Mills	20	20	20	20	20	20	'n
Counter Voltage	1575	1560	14900	1500	1500	1500	790
Counter	Gas-Flow	Gas-Flow	Gas-Flow	Gas-Flow	Gas-Flow	Gas-Flow	Scint.
PHA Window Volts	28.2	16.2	30.0	21.0	18.6	21.0	15.6
PHA Base Volts	4.2	1.8	4.2	3.0	5.4	9.0	2.4
Path	Vacuum.	Vacuum	Āir	Vacuum	Vacuum	Vacuum	Vacuum
Anelyz- ing Crystal	EDDT	EDDT	EDDT	EDDT	EDDT	EDDT	Lif
20 A	107.98"	142.52°	23.01°	50.28°	44.84°	36.37°	62.91°
Chara- teristic Radia-	×°	Ка	ж В	8	×	ಶ ಜ	ಶ ಜ
Triget Excita- tion	W 50KV 35m A	50KV 35m A	50КV 35т А	50кv 35m A	50KV 35mA	9 50KV 35m A	W 50KV 35mA
Ele- ment	St	A 1	Fe	×	Ca	11	X

1) Vacuum - 0.4 - 0.5 mm Hg

2) Gas-flow proportional counter using P-10 gas (90% Ar + 10% CH $_4$) at a flow of 0.4 SCFH/air

determined from which the percent composition of the element was calculated.
4) The standard and relative deviations were calculated from the composition.

SILICA (SiO₂), IRON (Fe₂O₃), POTASSIUM (K_2 O), CALCIUM (CaO) & TITANIUM (TiO₂)

Using the recommended values for G-1 and W-1 (Stevens and others, 1960), the SiO₂, Fe₂O₃, K₂O, CaO and TiO₂ content were determined by the fixed count-two point calibration curve procedure. Since the peak to background ratios were high for these elements and since the Shoal samples have a similar matrix to G-1, the background was not subtracted from the counts in determining the intensity ratios.

No contamination of titanium was noted in the iron ground or the ceramic ground pellets. Therefore, the iron ground pellet was used because most of the other determinations were made from these pellets.

Table 7 shows the percent composition for these elements and Table 8 shows the statistical analysis.

MANGANESE (MnO)

A fixed time procedure was used in determining manganese due to the low amount present which would have required a long counting time.

Also, because of the low peak to background ratio, background readings were taken 1° 29 on each side of the peak and in each case, the average background count was subtracted from the peak count before calculating the intensity ratio.

Again the recommended values for G-1 and W-1 were used for the calibration curve. See Tables 7 and 8 for percent composition and statistical analysis.

ALUMINA (A1203)

Silica enhances the aluminum radiation and if plotted directly, a negative calibration curve would result. To correct for this effect, the following procedure was used. The intensity ratios are still based on G-1 and in addition the standard Syenite 1^a, (Nonmetallic Std. Comm. Report 1961) was used. By extrapolating a curve between the points of W-1 and 1^a, the influence of the enhancement of the 20.01% difference between G-1 and W-1 was calculated to be 0.80% Al₂0₃. A proportion was then established to calculate the influence of different amounts of silica as it varies with W-1.

Example: $\frac{\text{(Diff of W-1 to } 1^{a}) = 5.68}{\text{(Diff of W-1 to } 7-1)=20.01} \times 0.80 = 0.23\% \text{ (Syerite } 1^{a}\text{)}$

TABLE 7
PERCENT COMPOSITION
SHOAL GRANITE SAMPLES

	si0 ₂	A1 ₂ 0 ₃	Fe ₂ ⁰ 3	K ₂ 0	CaO	T102	Mn0
1.	69.27	14.83	2.34	2.97	2.53	0.30	0.057
2.	70.13	14.61	2.22	2.91	2.53	0.28	0.054
3.	69.54	14.70	2.25	3.30	2.24	0.31	0.046
4.	70.57	14.46	2.14	3.04	2.40	0.27	0.053
5.	70.86	14.27	2.01	3.02	2.42	0.26	0.046
6.	69.07	14.05	2.08	3.05	2.41	0.25	0.051
7.	68.37	15.21	2.62	2.75	2.74	0.33	0.062
8.	69.37	15.21	2.25	3.46	2.45	0.28	0.053
9.	71.00	14.47	1.93	3.29	2.27	0.24	0.049
10.	69.47	14.68	1.97	3.16	2.26	0.28	0.048
11.	69.74	14.81	2.24	3.03	2.49	0.31	0.057
12.	68.10	14.98	2.78	3.95	2.43	0.41	0.066
13.	68.64	15.12	2.65	3.25	2.67	0.35	0.062
14.	68.29	15.06	2.56	2.78	2.78	0.33	0.058
15.	69.37	15.00	2.26	2.92	2.69	0.28	0.051
16.	68.45	15.13	2.32	3.13	2.68	0.31	0.053
17.	69.19	15.01	2.23	2.87	2.69	0.30	0.054
18.	68.29	15.29	2.88	3.29	2.68	0.36	0.064
19.	67.56	14.46	2.12	3.30	3.01	0.30	0.054
20.	68.88	15.14	2.19	3.94	2.44	0.31	0.053
21.	69.80	15.04	2.28	2.99	2.71	0.31	0.054
22.	69.32	15.18	2.20	3.13	2.69	0.33	0.052

TABLE 7
PERCENT COMPOSITION
SHOAL GRANITE SAMPLES

	sio ₂	A1 ₂ 0 ₃	Fe ₂ 0 ₃	к ₂ 0	Ca0	T10 ₂	Mn0
23.	69.03	15.40	2.44	3.37	2.57	0.35	0.056
24.	68.32	15.25	2.44	3.31	2.63	0.35	0.057
25.	67.32	15.39	2.76	2.84	2.80	0.38	0.062
26.	69.48	15.10	2.07	3.12	2.40	0.32	0.044
27.	66.19	14.54	2.15	2.05	3.34	0.36	0.057
28.	67.37	15.22	2.48	2.40	3.11	0.38	0.051
29.	68.26	15.04	2.32	3.13	2.65	0.32	0.052
30.	68.45	14.83	2.40	3.14	2.59	0.33	0.056
31.	67.32	15.11	2.91	2.81	2.64	0.40	0.059
32.	67. 6 9	15.54	22	3.36	2.65	0.38	0.053
33.	68.49	15.10	2.35	3.22	2.59	0.33	0.052
34.	67.42	15.46	2.65	3.68	2.66	0.41	0.060

TABLE 8
STATISTICAL ANALYSIS

	28 CR	٥. ۶	% Composition	n Ave	Standard Deviation	tion	Re	Relative Deviation	eviati		
	70			. av 6.	AVAILE C	. W. W.	Maribe			۸۷ ۱	
S10 ₂	66.19 7 - 71.00	- 2	71.00 %	68.78%	0.03 - 0.27	0.14	0.04	0.04 % - 0.38	ĸ	0.20 %	K
A1 0	14.05	ı	- 15.54	14.96	0.01 - 0.15	90.0	0.07	- 0.97		0.42	
Fe_03	1.93	1	2.91	2.35	0.000 - 0.65	0.018	0.00	- 2.36		0.78	
K ₂ 0	2.40	ı	3.95	3.12	0.007 - 0.041	0.015	0.22	- 1.23		0.49	
CaO	2.24	ı	3.34	2.61	0.000 - 0.030	0.01	0.00	- 0.93		0.42	
r10 ₂	0.24	ı	0.41	0.32	0.000 - 0.007	0.003	0.00	- 2.54		66.0	
Mn0	0.044	ı	990.0	0.054	0.0000- 0.0016	0.0007	000.0	- 0.629		0.012	

A second calibration curve was then constructed from which the enhanced alumina content was determined. The correction factor, determined from the above proportion, was then subtracted giving the corrected value.

Example: Ratio
$$\frac{G-1}{1a}$$
 = 0.6731

From cal. curve 11_20_3 - 9.55%
Less - 0.23

Corrected value - 9.32% (Syenite 1a)

The correction factors for the Shoal samples varied from 0.54% to 0.73% ${\rm Al}_2{}^0$ depending on the amount of silica present.

See Tables 7 and 8 for percent composition and statistics analysis.

COMPOSITION VARIATION

Figures 19 and 20 show the chemical composition plotted vs. the sample number to give a graphical presentation of the variation. It i; not the intent of this section of the report to draw any geochemical conclusions from this variance, but in general it can be seen where the silica content decreases, the alumina content increases. Also, at sample #27 (1653 feet-1654 feet), the composition varies greatly. From the core log, it was seen that this section was in a fault zone.

CONCLUSIONS

X-ray spectroscopy affords the analytical chemist with a tool by which a large number of samples can be analyzed utilizing speed, simplicity, a non-destructive technique and achieving good precision. Also, accuracies as good as with chemical methods are obtained (Volborth, 1963). The precision obtained for these samples was very good.

The analysis of these samples will be continued and it is planned to determine the oxygen content by neutron activation (Volborth, 1963) and to analyze for sodium and magnesium by ultrasoft X-ray techniques. Results of this work may later be published.

REFERENCES

Nonmetallic Standards Committee, Canadian Association for Applied Spectroscopy Report, 1961: Applied Spectroscopy, v. 15, no. 6, p. 159-161.

Stevens, R.E., and others, 1960, Second Report on a Cooperative Investigation of the Composition of Two Silicate Rocks: U.S. Geol. Surv. Bull. 1113.

Volborth, A., 1963, Total Instrumental Analysis of Rocks: Nevada Bur. Mines, Report 6.

Volborth, A., and Banta, H.E., 1963, Oxygen Determination in Rocks, Minerals and Water by Neutron Activation: Anal. Chem. v. 35, No. 13, p. 2203-2205.

	,		
	·	1 1	, , , , , , , , , , , , , , , , , , ,
			2
		<u> </u>	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
	<u> </u>	 	
			── ₩
	P		
			
		-	r %
	 -		× ×
	 	-	S2
) ——	 	-	**************************************
— —	<u> </u>	·	53
			25
			
,			2 8
			Ä.
			3 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
			77 18 12 20 2
			
		•	SAMPLE SAMPLE
	 	-	5 & S
<u> </u>			•
		-	2
<u> </u>			l =
<u> </u>			= 5
-			
_		-	<u> </u>
<u> </u>		 	
ļ	}	— —	,
-	,		
		Ι	l l
·			•

		·	
			200 000 000 000 000 000 000 000 000 000
ç % ç %	% K ^{\$} 0	ε0sIA % δ δ	201S %
090%	% K ⁵ O	€OSIA %	Sois %

213

Trace Elements In Shoal Granite Samples by A. Volborth, H. A. Vincent, and P. A. Weyler

INTRODUCTION

Analysis of the Shoal drill core samples of granite for trace elements was undertaken to complement the chemical analysis by the X-ray spectrographic determination of the major rock constituents and also to show, by comparison of the quantities of each element present with respect to its depth in the drill hole, the vertical variations of the trace elements in this rock.

Determination of the trace elements in rocks by X-ray methods has been difficult in the past because of dilution effects induced when customary fusion techniques are used. The method developed by Volborth (1963) and used in the work on the major constituents of Shoal granite, reported in the preceding section, involves no dilution when the pellet is made directly from the rock powder. Thus the method should have an advantage over those involving dilution in determining elements present in trace amounts.

The technique involving preparation of a plain-glass-pressed pellet from the unfused rock sample was used in the present study to determine scandium, titanium, vanadium, chromium, manganese, copper, zinc, rubidium, strontium, yttrium, zirconium, molybdenum, silver, antimony, cesium, barium, lanthanum, cerium, neodymium, samarium, gadolinium, hafnium, and mercury.

PROCEDURES AND RESULTS

The determinations were made on composite samples prepared by mixing equal-sized portions (100 grams) from each of the 50 foot interval samples from drill Hole ECH-D. One composite sample was prepared from rocks pulverized solely with iron plates and another sample was prepared from rocks ground using ceramic plates only.

Standards were prepared by adding pure oxides of the elements to a mixture consisting of 80% SiO₂ and 20% Al₂O₃ thus roughly approximating the composition of the granite being analyzed. Emission intensity versus concentration plots were assumed to be linear in the ranges considered. The detection limits, using the equipment as described by Volborth (1963), vary between 10 and 100 ppm for most of the elements with a precision of determination in the 1-10% range for relative standard deviation.

The accuracy of the method was checked by comparison with standards G-l and W-l, the former being used predominantly because of its similarity in composition to the Shoal granite. Recommended values of data reported in the literature for G-l and W-l were used for the standard values. The fact that for 23 elements the G-l points fell on or very close to the calibration curve based on the "pseudo" granite lends credence to the advisability of using the artificial standard approach.

The results of the trace element determinations by X-ray emission spectroscopy on Shoal composite samples are given in Table 9 in order of the increasing atomic number of the elements. Instrumental parameters are included, where important, such as the collimation used between the samples and the detector. The type of crystal used for each determination is also listed. Pellet numbers 607-610 were prepared from ceramic-ground rock powder while pellets 613-616 were made using iron-ground rock powder.

In some instances values for an elemental concentration were found using the calibration curve for the "pseudo" granite and also values were calculated from the ratio of counts for the G-l pellet and the composite sample pellet. In other situations the G-l value fell exactly on the artificial standards curve and only one value was calculated for the composite sample. The results for copper represent an example of the latter case.

Where possible the deviation for the 99% confidence level (3 S) is given as well as the range for the relative standard deviation when several types of determinations were carried out.

Where the limit of detection was approached and the calibration curves were not applicable, the peak height of the energy distribution scans were used assuming a linear relationship between peak height and concentration. Approximate detection limits under the instrumental conditions used are also given in Table 9.

The distribution of 13 of the trace elements: Titanium, vanadium, manganese, copper, zinc, rubidium, strontium, yttrium, zirconium, barium, lanthanum, cerium and gadolinium, according to depth in the drill hole ECH-D was followed by comparing characteristic emission intensities for pellet samples of the 50 foot intervals with those intensities for the composite sample pellet 607. The ratios of these intensities were plotted versus sample number where the sample numbers from 1 to 34 represent the 50 foot interval sampling described in the previous section on the major constituents. The variation of the intensity ratio represents change in concentration and it is this change in concentration which is shown as the ordinate in Figures 21-33, pages 225 through 239.

The variation span as shown on the ordinate of each of the figures was calculated by assuming that the background counts remain a certain percentage of the total counts even though the physical conditions may vary slightly. The number of counts due to the presence of the element sought may thus be calculated and for the pellet 607 the quantity of element present was calculated from the calibration curve for that element. The comparison pellet 607 was run along with each series of the drill hole sample pellets. A ratio of total counts for a sample pellet with respect to pellet 607 is plotted and the background is assumed to be the same for both pellets. Calculation of the span is perhaps more easily shown by an example: Assume that for pellet 607, 50% of the total counts are due to background and 50% are due to presence of the element. If the ratio of counts for another pellet compared to 607 is 1.1 then 600 counts of every 1100 total counts are due to the sought element and 500 are due to

TABLE 9 PROJECT SHOAL TRACE ELEMENTS BY X-RAY EMISSION SPECTROSCOPY

21 Sc

Based on our calibration curve:

Shoal Composite, Cer. Plates, 607 Shoal Composite, Fe Plates, 613 10 ppm 10 ppm

Dectection limit ~ 5 ppm

Based on G-1, EDDT crystal:

Shoal Composite, Cer. Plates, 607

Shoal Composite, Fe Plates, 613

--5 ppm

5 ppm

22 Ti

Based on our calibration curve alone, LiF crystal:

Shoal Composite 607-10 and 613-16 1540 ppm 3S = ± 100 ppm

Detection limit ~10 ppm

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 1680 ppm 3S = - 100 ppm

C = 2%

23 V

Based on our calibration curve, LiF crystal, 20 mil. collim .:

Shoal Composite, Cer. Plates, 607-10 50 ppm $3S = \frac{1}{2} 2 \text{ ppm}$ Shoal Composite, Fe Plates, 613-15 50 ppm $3S = \frac{1}{2} 2 \text{ ppm}$

C = 1-2%

Based on G-1, EDDT crystal 5 mil. collim.:

Snoal Composite, Cer. Plates, 607-10 65 ppm $3S = \frac{1}{2}$ 13 ppm Shoal Composite, Fe Plates, 613-16 65 ppm $3S = \frac{1}{2}$ 6 ppm

C = 2.6 - 6.6%

Detection limit ~10 ppm

TARLE 9 (Continued)

Based on our two point calibration curve, G-1 and W-1, EDDT crystal, 20 mil. collim.:

Shoal Composite, Cer. & Fe, 607-613

40 ppm 3S = \pm

3 рры

24 Cr

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607 10 ppm Based on energy distrib. curves, 607,613 20 ppm

Detection limit ~10 ppm

25 Mn

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim:

Shoal Composite Cer. Plates, 607-10 370 ppm $3S = \frac{1}{2}$ 35 ppm Shoal Composite Fe Plates, 613-15, 618 390 ppm $3S = \frac{1}{2}$ 35 ppm

C = 1-3%

Detection limit ~10 ppm

29 Cu

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim .:

Shoal Composite, Cer. Plates 607-10

Shoal Composite, Fe Plates 613-16

18 ppm 3S = ± 2 pp 3S = ± 2 pp

C = 1-3%

Detection limit ~10 ppm

30 Zn

Based on our calibracion curve and G-1, LiF crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 55 ppm $3S = \frac{1}{2}$ 3 ppm Shoal Composite, Fe Plates, 613-16 52 ppm $3S = \frac{1}{2}$ 3 ppm

C = 1.4-2%

Detection limit ~10 ppm

37 Rb

TABLE 9 (Continued)

Based on our calibration curve, G-1 and W-1, LiF crystal, 5 mil. collim:

Shoal Composite, Cer. Plates, 607-10 130 ppm $3S = \frac{+}{2}$ 5 ppm Shoal Composite, Fe Plates, 613-16 120 ppm $3S = \frac{+}{2}$ 10 ppm

C = 1.3-2.6%

Detection limit ~10 ppm

38 Sr

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 880 ppm $3S = \frac{+}{-}$ 50 ppm Shoal Composite, Fe Plates, 613-16 875 ppm $3S = \frac{+}{-}$ 50 ppm

C 2%

Detection limit <50 ppm

39 Y

Based on our calibration curve and G-1, LiF crystal, 5 mil. collim.:

Based on energy distribution curves:

C = 3%

Detection limit -~ 5 ppm

40 Zr

Based on our calibration curve, LiF crystal, 5 mil. collim .:

Shoal Composite, Cer. Plates, 195 ppm 3S = 12 ppm Shoal Composite, Pe Plates, 175 ppm 3S = 21 ppm

G-1, on this curve 243 ppm $3S = \pm 15$ ppm G-1, recommended 210 ppm

G-1, range in reported data for Zr 100-326 ppm

C = 2-4%

Detection limit ~10 ppm

42 Mc

TABLE 9 (Continued)

Based on energy distribution curves, LiF crystal, 5 mil. collim;

Shoal Composite, Cer. and Fe Plates

Not Detected

Detection limit ~50 ppm

Interference from Mo in the system

47 Ag

Based on energy distribution curves:

Shoal Composite, Cer. Plates, 607-10 Shoal Composite, Fe Plates, 613-16

Not Detected

Detection limit in granitic rocks ~100 ppm

51 So

Based on energy distribution curves, LiF crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 Shoal Composite, Fe Plates, 613-16 Not Detected

ondi composite, re l'acce, vis i

Detection limit in granitic matrix ~50 ppm

55 Cs

Based on energy distribution curves, EDDT crystal, 20 mil. collim.:

Swoal Composite, Cer. Plate, 607

Not Detected

Shoal Composite, Fe Plate, 613 Not Detected

Detection limit using L radiation in granitic matrix -100 ppm

56 Ba

Based on our calibration curve, settings same:

Shoal Composite, Cer. Plates, 607-10

 $\frac{1080 \text{ ppm}}{1000 \text{ spm}}$ 3S = $\frac{1}{2}$ 65 p

Shoal Composite, Fe Plates, 613-16 1070 ppm 3S = 2 65 ppm

Based on G-1 and blank, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10

1455 ppm

 $3S = \frac{+}{2} 90 \text{ ppm}$

Shoal Composite, Fe Plates, 613-16 1445 ppm 3S = 90 ppm

C = 2.1

Detection limit ~100 ppm (L)

57 La

TABLE 9 (Continued)

Based on our calibration curve and G-1, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plate, 607
Shoal Composite, Fe Plate, 613
75 ppm
75 ppm

Based on our calibration curve and G-1, EDDT crystal, 20 mil. collim.;

Shoal Composite, Cer. Plates, 607-12 85 ppm $3S = \frac{1}{2}$ 6 ppm Shoal Composite, Fe Plates, 613-16, 618 75 ppm $3S = \frac{1}{2}$ 9 ppm

C = 2.3-3.9%

Detection limit ~10 ppm

58 Ca

Based on our calibration curve, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 $\frac{1180 \text{ ppm}}{1155 \text{ ppm}}$ $3S = \frac{+}{2} 120 \text{ ppm}$ Shoal Composite, Fe Plates, 613-16 $\frac{1155 \text{ ppm}}{1155 \text{ ppm}}$ $3S = \frac{+}{2} 80 \text{ ppm}$

G-1 on our calibration curve 1300 ppm G-1 Adler et. al. 1050 ppm G-1 Mean of reported data 600 ppm

C = 2.2-3.4%

Detection limit ~10 ppm

Based on cur calibration curve, EDDT crystal, 20 mil. collim.:

Shoal Composite, Cer. Plates, 607-12 1075 ppm $3S = \frac{+}{2}$ 32 ppm Shoal Composite, Fe Plates, 613-17 1055 ppm $3S = \frac{+}{2}$ 74 ppm

C = 0.9-2.4%

Detection limit ~10 ppm

60 Nd

Based on our calibration curve and G-1, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607-10 < 80 ppm Shoal Composite, Fe Plates, 613-16 < 80 ppm

Based on energy distribution curves, EDDT crystal .:

Shoal Composite, Cer. Plates, 607-10 ~40 ppm Shoal Composite, Fe Plates, 613-16 ~40 ppm

C = 5% Detection limit ~40 ppm

62 Sm

TABLE 9 (Continued)

Based on our calibration curve:

Shoal Composite, 607, 613

None Detected

Based on energy distribution curves and assuming linear relationship:

Shoal Composite, Cer. Plate, 607 Shoal Composite, Fe Plate, 613

50 ppm 50 ppm

G-1 value based on our calibration curve

20 ppm

Detection limit ~10 ppm

64 Gd

Based on our calibration curve, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plates, 607, 608 Shoal Composite, Fe Plates, 613, 614

45 ppm 35 ppm

G-1 value based on our calibration curve

45 ppm

Detection limit ~10 ppm

72 Hf

Based on our calibration curve, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plate, 607 Shoal Composite, Fe Plate, 613

Not Detected Not Detected

Detection limit ~10 ppm

Based on energy distribution curves:

Shoal Composite, Cer. Plate, 607 Shoal Composite, Fe Plate, 613

Detected 90 ppm

80 Hg

Based on energy distribution curves, EDDT crystal, 5 mil. collim.:

Shoal Composite, Cer. Plate

Not Detected

Detection limit in granite matrix ~900 ppm

background as in the reference pellet 607. If the counts increase linearly with concentration then the amount of the element in the sample pellet must be 6/5ths the amount in the reference pellet 607. If the ratio had been 0.90 for this example then the amount of the sought element would have been 4/5ths that in the reference pellet 607, showing that the variation is linear with respect to ratio on the ordinate scale. The actual value in parts per million for the sample was not plotted because then all the values would be dependent on the value obtained for the reference whereas the variation value is not so sensitive to a change in absolute value for the reference. The change is probably more valuable for geochemical studies than are the absolute numbers and the change is more easily obtained.

The insert graph in each of the figures shows the variation in intensity ratio compared to pellet numbe. 607 for other pellets prepared from ceramic and iron ground powders for the composite samples. The scale is the same for Figure A and B. These data indicate precision possible when data are taken from several pellets and include contributions to the analytical precision data from both instrumental and sample preparation deviations. In order for the analytical results to be non-random in character and significant for geochemical purposes, the variation between the results for pellets of one kind of sample must be much less than the variation noted with the different drill hole interval samples.

Sample pellets from 607 to 612 were prepared from the ceramic-ground composite powder while those from 613 to 618 were made from the iron-ground composite sample powder. A definite shift toward higher or lower values of a particular element for the ceramic-ground compared to the iron-ground sample pellet can be noted in several instances. This results from contamination in the sample preparation process. The pellets used for the element distribution studies were all prepared from the iron-ground powders.

The practical use of the X-ray method for these traces is well demonstrated here by the precision achieved. The geochemical interpretation of the distribution data is a very difficult problem and will require subsequent treatment for completeness and will obviously need to include use of computors for the handling of the amassed statistics. In comparison between figures 19 through 33 a number of interesting observations should be noted even though no complete interpretation is attempted. The titanium and vanadium concentration vary strikingly in the same manner for each pellet. Zinc and copper show some extreme changes in concentration for individual drill hole samples but the changes show no correlation in distribution between the two elements. Values for the lower part of the drill hole show that the amount of potassium present is slowly increasing with depth while the amount of rubidium present appears to decrease in the same region. The amount of zirconium present appears in most cases to vary oppositely to the changes in the silica content. The variation in barium is much more irregular with drill hole depth and with a more extreme pattern than the changes for either strontium or calcium.

Three elements found in trace quantities in this type of rock and which could not be determined by the X-ray method were determined in the composite samples by other techniques. The results are given in Table 10.

Although there are still some more analytical projects to be carried out with the Shoal granite, such as the determination of the oxygen distribution with depth and the determination of some of the light elements such as phosphorous and sulfur, it is probable that the Shoal granite represents a granite block as thoroughly analyzed as any in the world. An important by-product of this work will be that a valuable granite chemical standard will be available for our laboratory and others.

REFERENCES CITED

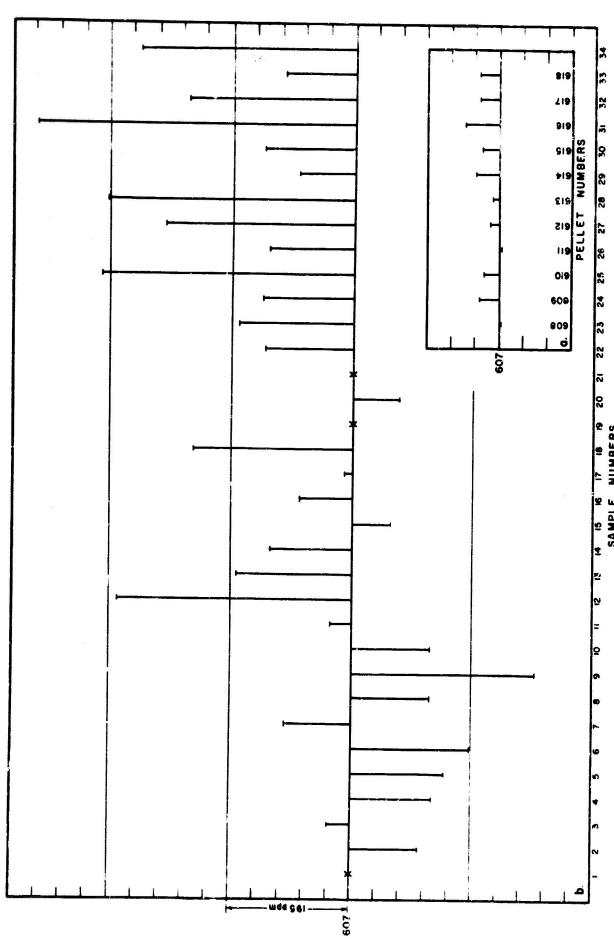
A. Volborth, 1963, Nevada Bureau of Mines Report 6A: Total Instrumental Analysis of Rocks; Mackay School of Mines, University of Nevada, Reno, Nevada.

TABLE 10
TRACE ANALYSIS OF SHOAL GRANITE
SAMPLES OTHER THAN X-RAY SPECEROGRAPHIC

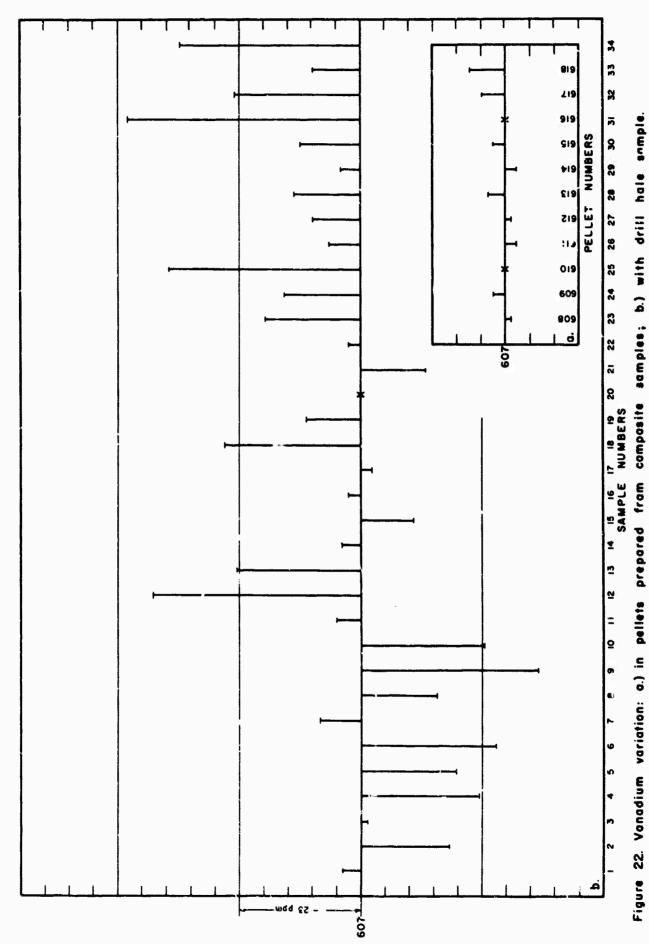
The following results are from the spectrographic and flame spectrophotometric studies on the Shoal composite samples.

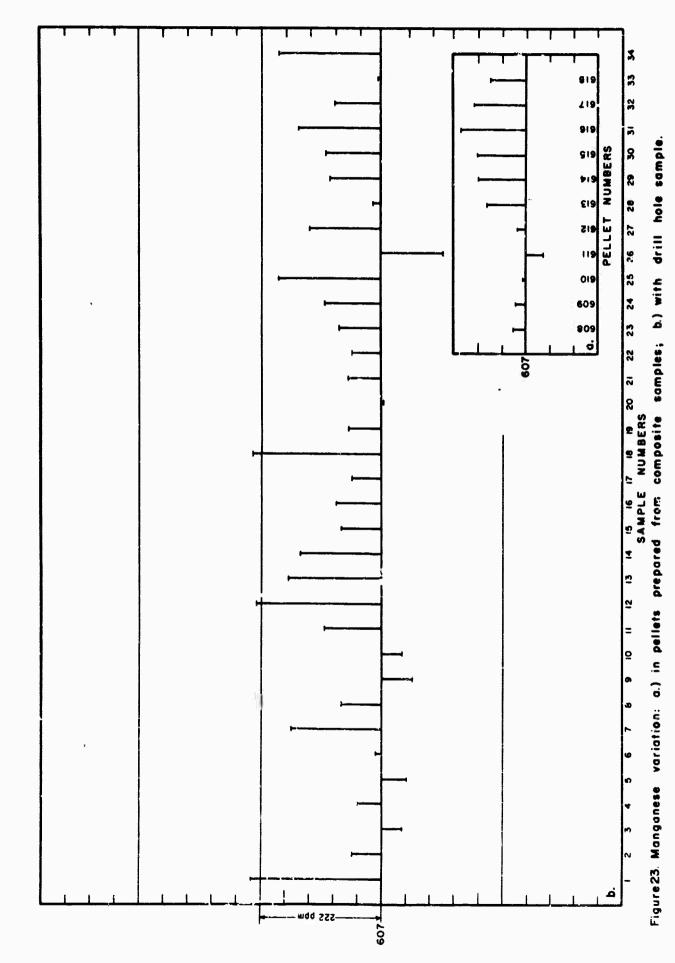
Sample	Li ₂ 0(ppm)	Li(ppm)	Boron (ppm)	Beryllium(ppm)
Shoal Comp. Fe Plates/Pica	52	24	5	<25*
Shoal Comp., Por Plates, Fisher Grinder	54	25	-	eq.
Shoal Comp. Por. Plates/Pica	56	26	-	-

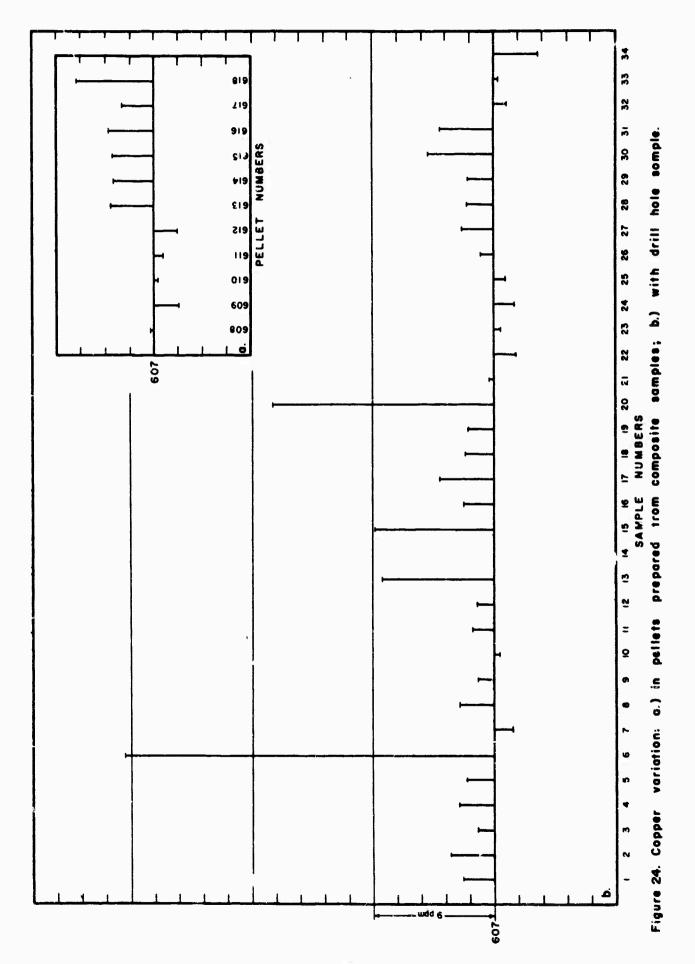
*None of the more sensitive lines were detected for Be in the Shoal sample. 25ppm Be is the approximate lower limit with our present analytical setup and this answer really means that if Be is indeed present then it must be lower than 25ppm.

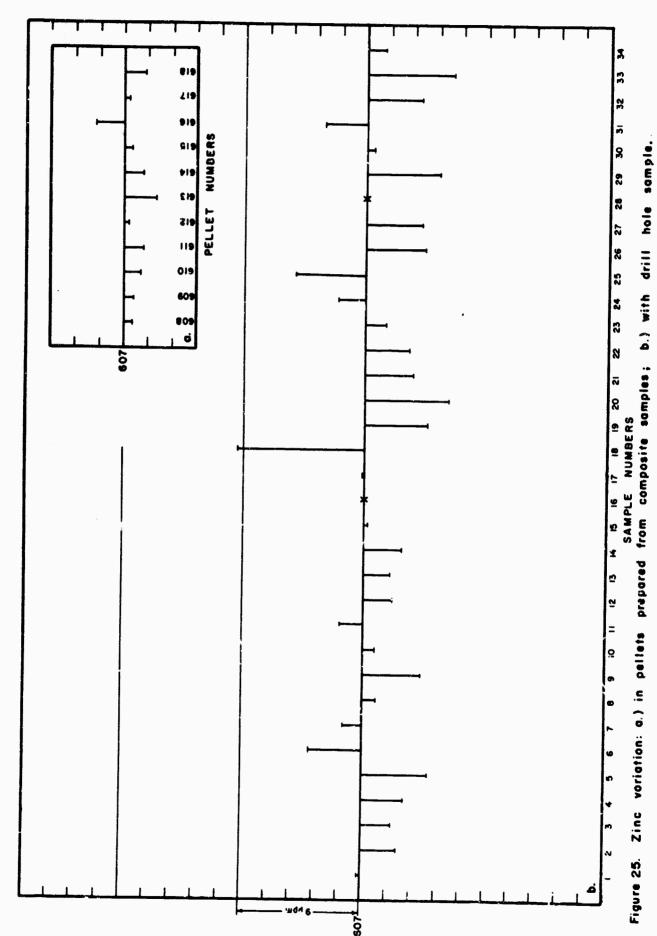


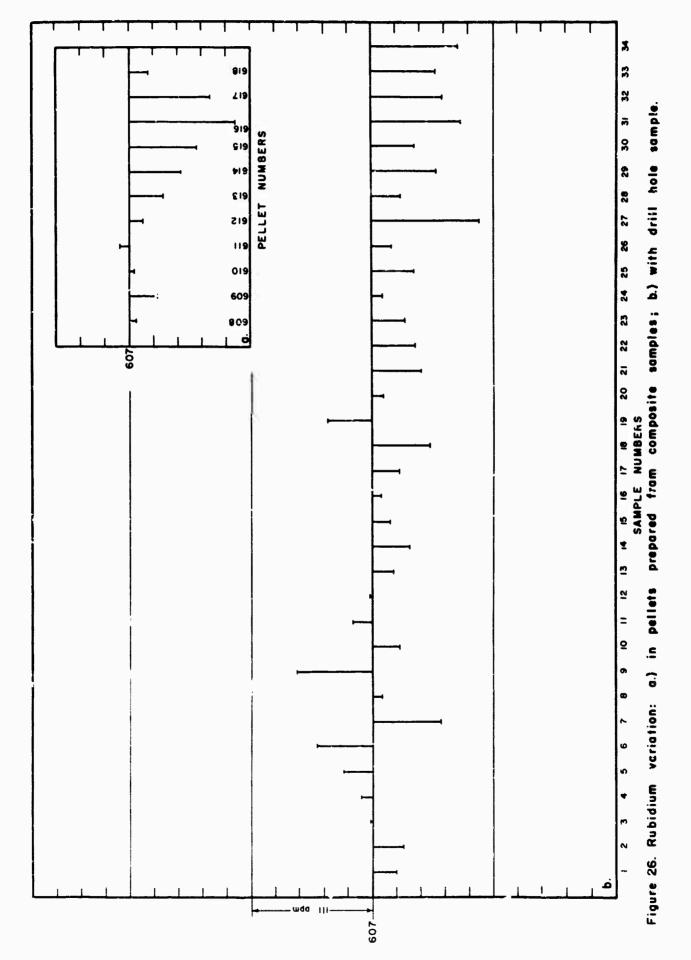
SAMPLE NUMBERS
Figu. e. 21. Titonium variation: a) in pellets prepared from composite samples; b) with drill hole sample.

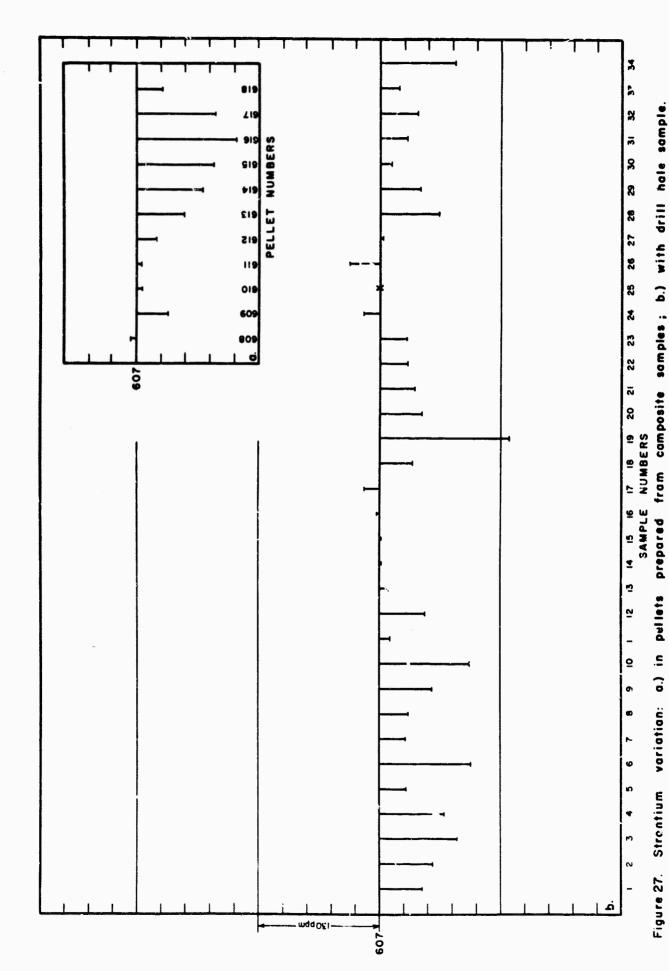


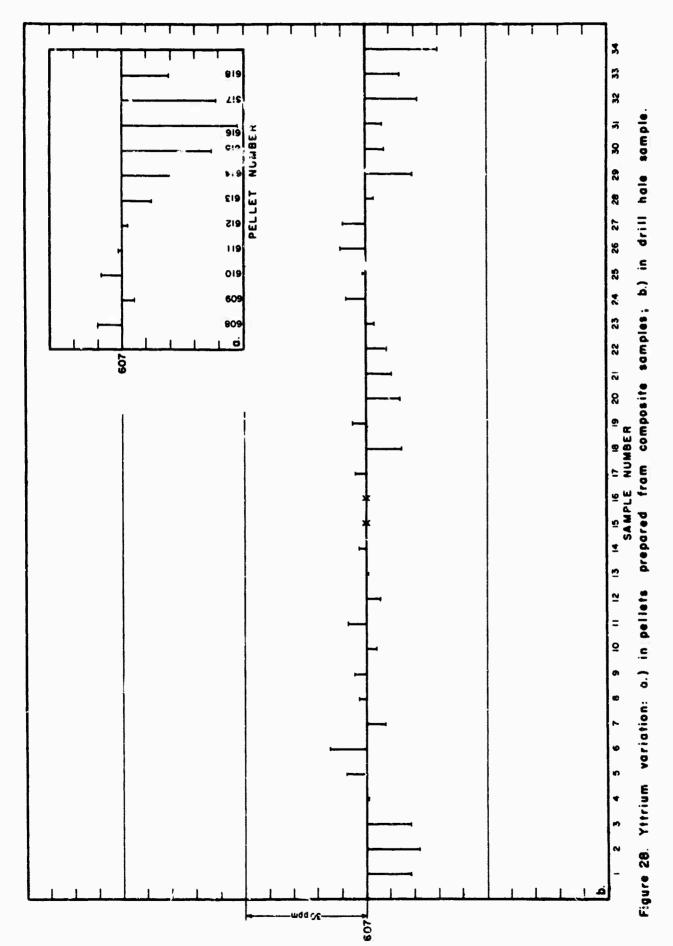


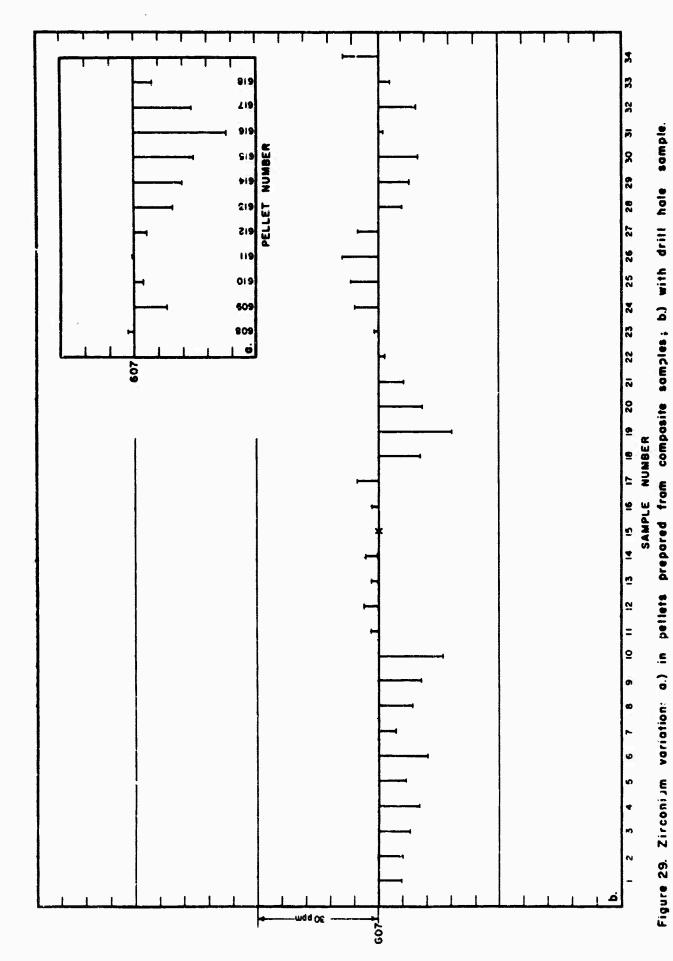












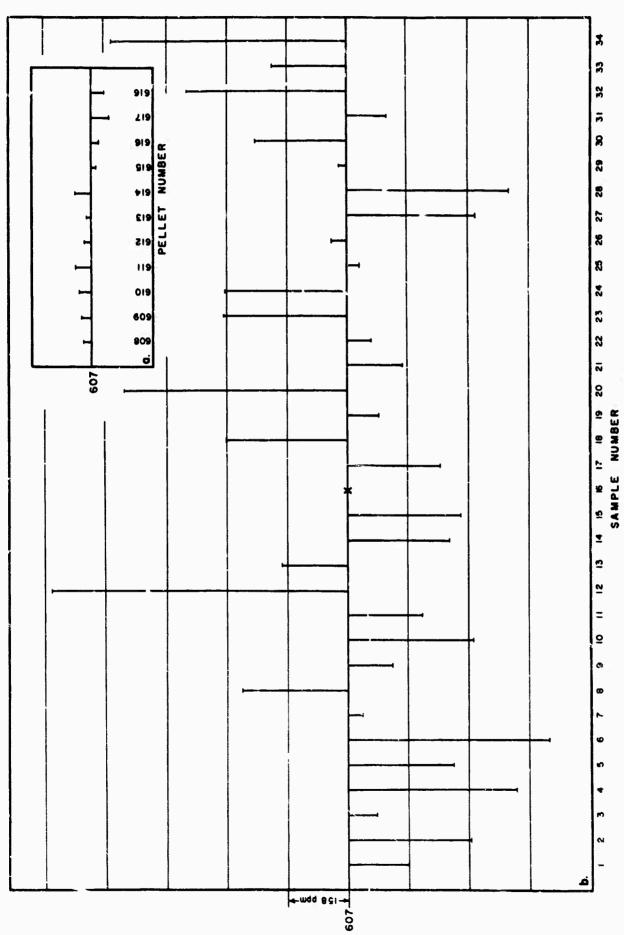
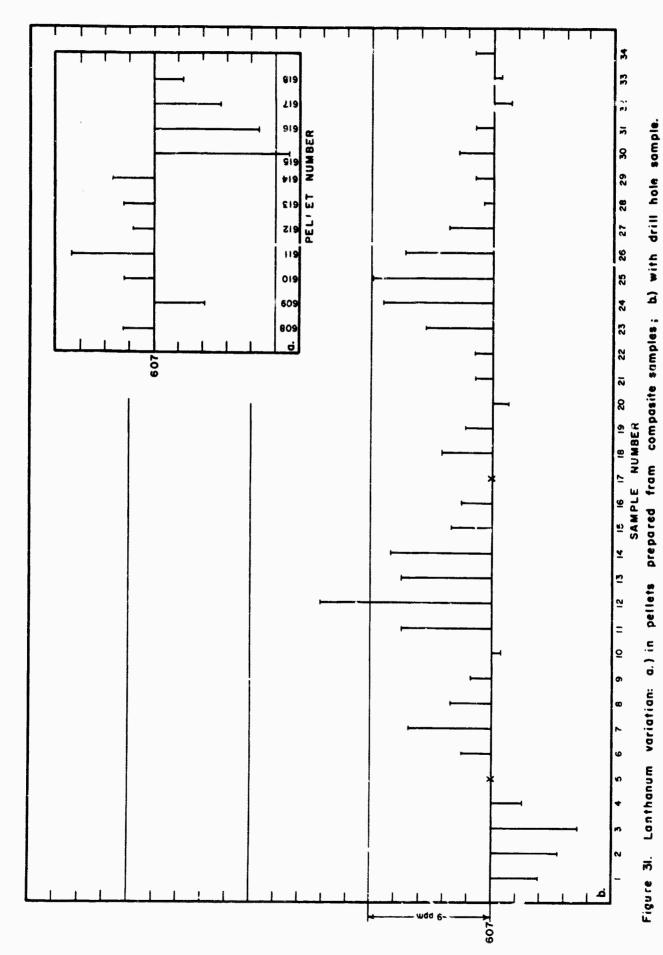


Figure 30. Barium variotion: a.) in pellets prepared from composite samples; b.) with drill hole sample.



Section 1 to the section of the sect

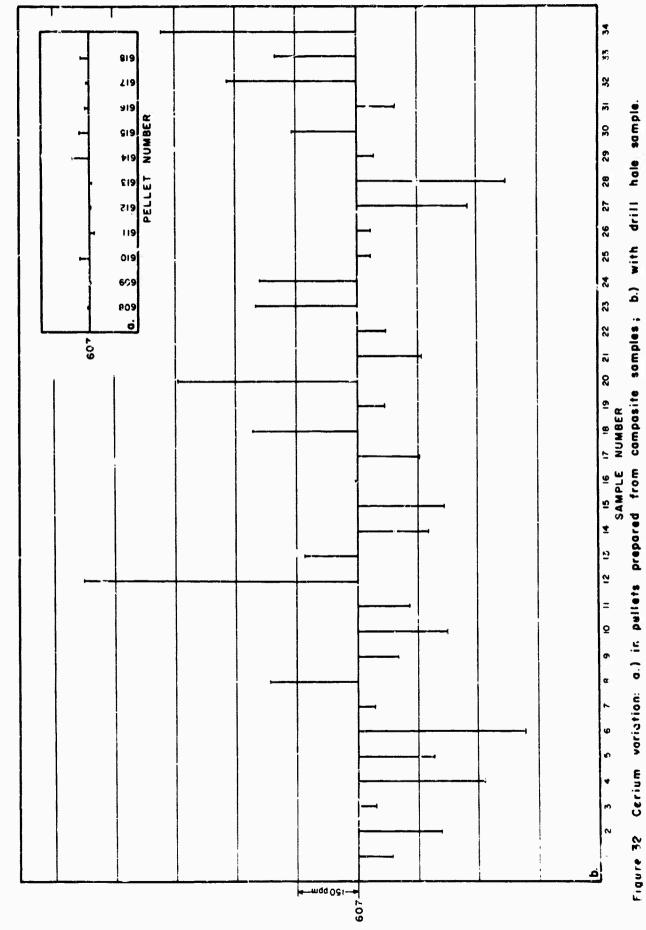
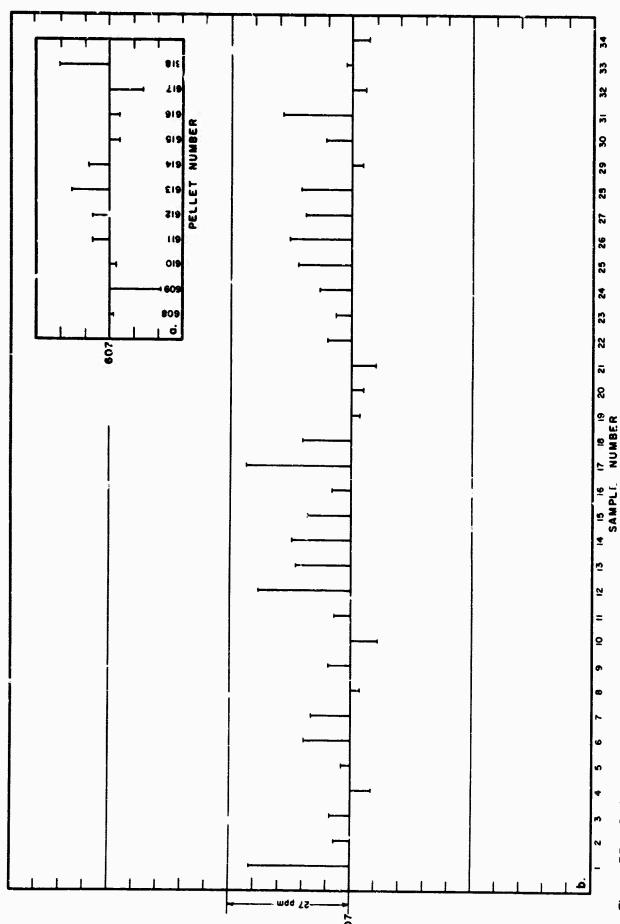


Figure 32



SAMPLE, NUMBER in pettets prepared from compasite samples; b.) with dritt hole sample. Figure 33. Godolinium variotion: 0.)

PART II

SHOAL OPERATIONAL STAGE

SECTION B

HYDROLOGICAL INVESTIGATIONS

OF THE SAND SPRINGS RANGE,

FAIRVIEW VALLEY, AND FOURMILE FLAT,

CHURCHILL COUNTY, NEVADA

BY

PERSONNEL OF
HYDROLOGY AND HYDROGEOLOGY SECTION
DESERT RESEARCH INSTITUTE

UNIVERSITY OF NEVADA

RENO, NEVADA

1964

PART II SECTION B

	rage
TABLE OF CONTENTS	
Acknowledgements	241
Introduction	241
Problem Approach	241
Pre-Shot Investigations	241
Detonation Studies	242
	242
Post-Shot Studies	242
•••	243
Lake Lahontan Geology	243
Fourmile and Eightmile Flats	249
Surface Geology	
Subsurface Geology	251
Fairview Valley	252
Surface Geology	252
Subsurface Geology	255
Supplement on the Occurrence of Ground Water	257
Springs and Seeps	257
Water Point 3	264
Water Points 6 and 7	264
Water Point 29	264
Water Point 30	265
Water Point 32	265
Water Point 40	265
Salt Farm 1, 2, 3	266
Hydrologic Tests in the Vicinity of Ground-Zero	266
ECH-D	266
PM-1	268
PM-2	268
PM-3	268
PM-8	271
USBM #1	271
Interpretations and Conclusion	271
Supplement on Chemical Data	275
Chemical Analyses	275
Tritium Analyses	279
Regional Flow Systems	282
Consequences of Shoal Event on the Water System	283
Preparations for Shoal Event Observations	283
Operational Procedures	283
Water-Level Monitoring in PM-1 and PM-2	284
Responses	286
Wiancko Gages in PM-1 and PM-2	286
Ground-Zero Water-Level Changes	290
	290 294
Leupold-Stevens Type F Recorders on H-2, H-3, and H-4 Other Measured Water Points	294 297
	297 298
Comparison of Detonation and Earthquake Fluctuations	
Summary of the Consequences	298
Conclusions	301
	4114

The second secon

	Page
Appendix G - Chemical Analyses of Water Points, Test Hole, and	
Surface Water Samples	305
Appendix H - Well Hydrographs Constructed on the Basis of Periodic	200
Measurements	308
ILLUSTRATIONS	
FIGURES	
1. Geology of the Valley Fill	244
2. Diagrammatic Sketch of Wash Bank Exposure of Lahontan Valley	
Group Sediments	247
3. Diagrammatic Cross-Section of the Shore Line Bar in	
Fairview Valley	253
4. Diagrammatic Cross-Section of Marginal Fault Contacts in	256
Fairview Valley	258
6. PM-1 Recovery Tests	269
7. PM-2 Initial Recovery Test	270
8. PM-3 Recovery Tests	272
9. U. S. Bureau of Mines Hole. Initial Recovery Test	273
10. U. S. Bureau of Mines Hole Final Recovery Test	274
11. Diagrams Showing Chemical Quality of Ground Water	277
12. General Geology and Supplementary Water Quality Diagrams	278
13. Wiancko Pressure-Response Gages as Deployed in Test Holes PM-1	
and PM-2 for Shoal Event	285
Recorded by Wiancko Pressure Gages	287
15. High Speed Hydrographs of Wells PM-1 and PM-2 During H-Hour	288
16. Hydrographs of the Bedrock Holes	291
17. Ground-Zero Area	293
18. Diagrammatic Hydrologic History of Bedrock Test Holes	295
19. Pre-and Post-Shot Hydrographs for Wells H-2, H-3, and H-4 with	
Barometric Curve	296
TABLES	
1. Water Wells and Springs Inventoried for Project Shoal	259
2. Tritium Analyses	280
3. Effect of Shoal Event on Water System as Indicated by	200
Instrumented Test Wells.	299

HYDROLOGICAI INVESTIGATIONS OF THE SAND SPRINGS RANGE, FAIRVIEW VALLEY, AND FOURMILE FLAT, CHURCHILL COUNTY, NEVADA

By

M. D. Mifflin, G. B. Maxey, P. A. Domenico, D. A. Stephenson and J. E. Hardaway

ACKNOWLEDGEMENTS

This portion of the final report deals with supplementary data, associated interpretations, and conclusions determined since Part I of this report was prepared. Most of the work has been done on a group basis under the direction of Dr. G. B. Maxey. Desert Research Institute personnel that have made contributions to the text are as follows: P. Domenico, J. Hardaway, G. B. Maxey, M. Mifflin, and D. Stephenson. In this report the final assembly of data and interpretations are those of M. Mifflin, with the general concurrence of G. B. Maxey and contributors. Drafting was done by R. Paul and K. Parrish.

INTRODUCTION

The conclusions offered in Part I states that there is little chance of ground-water contamination in environments other than those in close proximity to the detonation point of a nuclear device of the magnitude proposed. Data collected and analyzed since that time supports these conclusions and substantiates further that a pattern of flow exists in the mountain and valley environs that precludes contamination of ground water now being utilized. A brief summary of the methods employed in the hydrologic studies follows; the results of which, in part, appear in Part I and the rest in this section of the report.

It should be pointed out that many of the concepts put forth by this section of the report were utilized in Part I in the hydrology section. However, additional data and study permits new or modified conclusions and interpretations in some subjects of the report.

Problem Approach

<u>Pre-Shot Investigation</u>: Pre-shot studies involved the investigation of the determinable factors which were available initially, or became available during the course of geologic and hydrologic exploration programs. These consisted of the following:

- 1) Ground-water static level or potential measurements.
- 2) Chemical and radiological analysis of ground water.
- 3) Pump and bail tests to determine hydrologic properties in the various geologic media.
- 4) Mapping of distribution, character, and position of the various geologic media.

Initially, all natural and artificial points of ground-water discharge within a 15-mile radius of the test site were located and inventoried. This area was considered to offer an adequate margin of safety on the basis of reconnaissance studies of lithology, topography, and precipitation on which probable flow systems were evaluated. Dixie Valley was found to be a downgradient part of the flow system which rises in the test site region, therefore, several wells in the valley were monitored. The water points were considered in the following manner: Chemical and radiological analysis, potential of ground water and source of ground water. The first three factors provided a control to ascertain any test-induced effects at a later date.

Detailed geologic studies of the basin fill were made to determine as much as possible the extent and continuity of alluvial materials where the highest rates of ground-water movement occur. These surficial studies were supplemented by subsurface information.

A modest test-drilling program in the alluvial materials adjacent to the Sand Springs Range test site was conducted to determine the thickness and nature of the alluvium, as well as to provide wells which could be used for hydrologic tests necessary to ascertain hydrologic properties of the saturated materials. These test holes also provided needed information on the ground-water potential adjacent to the Sand Springs Range to aid in the definition of the ground-water flow systems.

Several deep exploratory and instrument holes were drilled in the granite of the test site and provided limited hydrologic data. Technical and economic problems, as well as hole purpose, limited the data which could be collected. However, adequate but not precise hydrologic data on the granite was obtained. After the construction and initial tests in each of the holes in the alluvium and bedrock, periodic sampling and monitoring programs were carried out where possible. Automatic recording devices were installed on several of the alluvium test holes to give records of water-level fluctuations.

<u>Detonation Studies</u>: In preparation for the detonation of the nuclear device, water-level monitoring devices were installed in some of the instrument holes in granite. The test holes H-2, H-3, and H-4 of the adjacent alluvial areas were equipped with a recording device to monitor water-level response during the shot. Two of these, H-3, H-2, and Water Point 2 at the edge of Fourmile Flat were also visually monitored during the detonation. Pre-shot polaroid photographs of inventoried springs or flowing wells were taken the day before detonation.

Post-Shot Studies: Post-detonation activities were carried out with the prime objective of ascertaining any effects upon water joints. Chemical and radiological samples as well as continued water-level measurements were collected. Post-shot photographs of all inventoried springs and flowing wells were taken the day after the detonation to use as evidence for any possible or alleged modifications including discharge. Several attempts to collect contaminated ground water from the re-entry hole have failed because of an obstruction above the possible saturated zone. Periodic chemical and radiological water-sample analysis will continue beyond the date of publication to ascertain possible long-term effects.

SUPPLEMENT ON THE GEOLOGY OF THE VALLEY FILL

Figure 1 is a geologic map of the alluvium contiguous to the Sand Springs Range and other bedrock areas. The two extensive areas of alluvium involved are the valley to the west which includes Fourmile and Eightmile Flats where extensive Late Pleistocene Lake Lahontan sediments occur, and Fairview Valley to the east where fluviatile sediments predominate. The alluvium adjacent to the Sand Springs Range contains ground water which is presently used and which may be developed more. Probability of contamination required a thorough investigation of occurrence, storage, and motion of this water. Detailed geologic studies as were made in the mountain range were therefore extended to the alluvium.

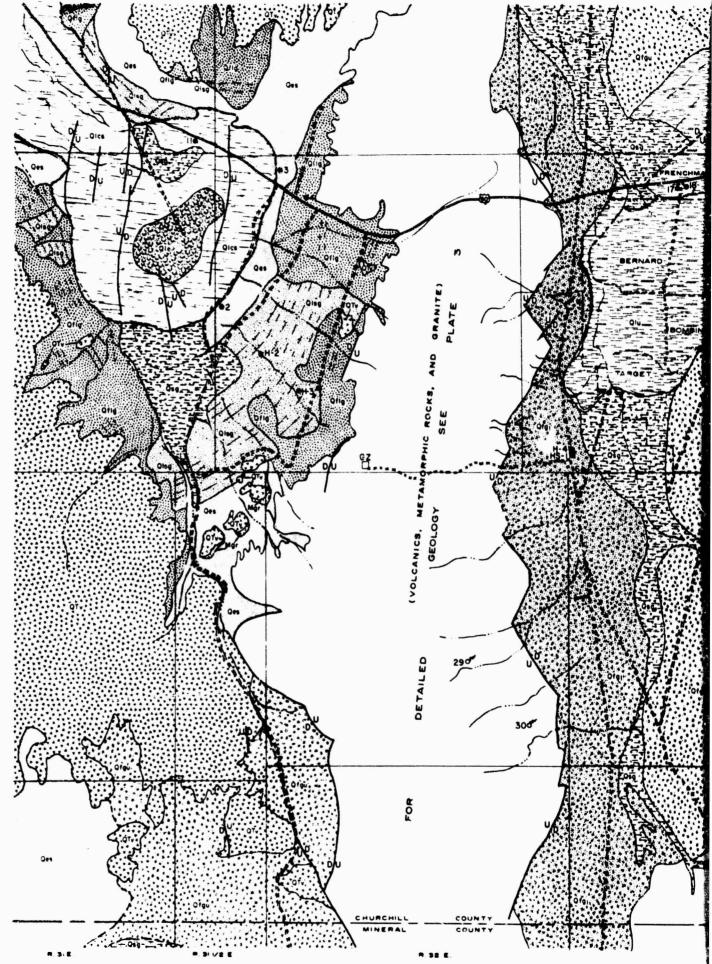
In arid basins which have been occupied by extensive lakes, the detailed hydrologic history (pluvial and fluvial cycles) may be of significance in the hydrologic regimen now observed. If, for example, the lakes were several hundred feet deep (Lake Lahontan was 500 feet deep in the central parts of numerous basins when at maximum stage), ground-water systems contiguous to the lakes would be greatly modified in configuration. Five hundred feet of increased head would exist in present areas of discharge, and a corresponding adjustment in the recharge areas would occur due to the increased discharge head and probable higher precipitation rates. In media of very low permeability, relict flow systems might conceivably be present today if these pluvial periods existed in very recent geologic times. For this reason considerable study was devoted to the Lake Lahontan deposits.

Lake Lahontan Geology

Morrison has put forth interpretations of the lake history in a series of publications (1961a, 1961b, 1964) and presently states that much detail now known is lacking in these publications (Morrison, 1964 personal communication). Figure 12, Part I is Morrison's published summary of the lake fluctuations and related deposits. Accordant knowledge gained in the fall of 1963 in detailed studies along the lower Truckee River north of the town of Wadsworth, Nevada is not included in the 1961a and 1964 publications. It has been found that several areas in western Nevada provide more favorable exposures of the Lake Lahontan sediments than those found in the Carson Desert and Fourmile and Eightmile Flats.

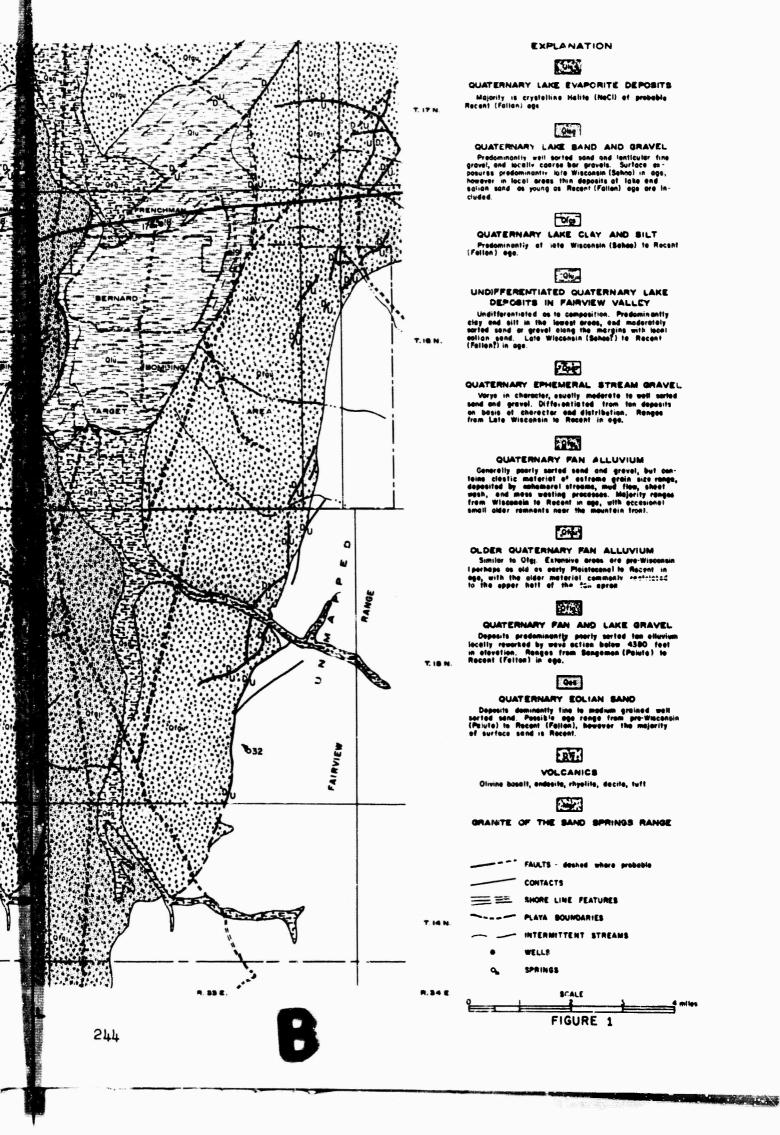
In the study done by the Desert Research Institute personnel, a serious effort was made to attain two objectives:

- 1) Ascertain the validity of Morrison's work and
- 2) extend the detailed mapping of the basin fill from that area mapped by Morrison (1964) to Eightmile and Fourmile Flats, as well as extend detailed differentiation of surficial deposits in Fairview Valley. These objectives were limited in realization by a number of factors such as time, funds, experience of available personnel, and the lack of adequate base maps and accurate topography. Therefore a number of modifications of the initial objectives resulted.



GEOLOGY OF THE VALLEY FILL





BLANK PAGE

A short discussion of problems encountered during the attempt to further Morrison's detailed mapping is appropriate. In attempts to make detailed studies of Lake Lahontan sediments many problems were encountered, with perhaps the foremost being the availability of exposures which have enough vertical and lateral extent so that stratigraphic position may be recognized by clearly-defined marker horizons. Ideally this type of exposure must be located in all environments of the depositional basin so that the maxima and minima of individual lake fluctuations can be delineated. Commonly lake units become fewer and decrease in thickness toward the higher elevations, and increase in number and thicken toward the center of the depositional basin. However, both in the center of the basin and high along the basin margin the exposures typically become rare or absent. Detailing the history of the lake fluctuations as well as of related hydrologic influences on the ground-water regimen becomes a monumental task, which can be accomplished only by the location and study of a sufficient number of key exposures encompassing the whole range of depositional environments.

Figure 1 is a geologic map developed primarily by photogeologic methods with extensive field checks. It differs markedly from the type of map Morrison compiled to the northwest in that different types of units are recognized. Morrison, whose prime interest was to determine the history of Lake Lahontan, necessarily had to differentiate age of deposits and interpret mode of deposition. This required that criteria to determine age be established for and applied to every deposit exposed at the surface within the depositional basin. Needless to say, careful mapping on a very detailed scale was required to carry known relationships over wide areas, and much additional interpretation was also necessary. An extensive background with the material at hand became of paramount importance to do a reasonable job.

It became apparent that such mapping of the alluvial basins adjacent to the Sand Springs Range would be questionable in accuracy and extremely time consuming in preparation. Therefore, as the prime interest was that of ground water, a map based essentially on lithology of the surficial deposits was compiled, with the age range of the deposits given. This type of map was deemed illustrative of what the subsurface distribution of materials might be, yet not misleading as to history of deposition.

In assigning age relationships to the various deposits, geosols are generally relied upon as marker horizons. Unfortunately, soil exposures are very sporadic, and many factors may influence the degree of development and preservation of the soils. Enough exposures were found, however, to elemtially verity Morrison's published findings with several minor exceptions. For a comprehensive discussion of the use of geosols in geologic work the reader is referred to Soil Stratigraphy, 1964, by R. B. Morrison (Ph.D. Thesis, University of Nevada and Nevada Bureau of Mines Memoir, in press).

In Fairview Valley an attempt was made to correlate geosols to those in the Lahontan Basin. This was done by comparing the degrees of development with consideration of the numerous influencing factors such as preservation, parent material, drainage and topographic position. Several soils were noted and tentatively correlated, but the degree of certainty is questionable because of the lack of any checks such as C₁₄ age determinations.

Figure 2 and the following discussion represent an exemple illustrating the analytic method for interpretation of field relationships in which we follow Morrison to determine the Lake Lahontan lake-cycle history. The exposure, occurring in Section 15, T. 17 N., R. 31 E. on the margin of Eightmile Flat, is included in the report to illustrate the criteria, assumptions and kind of interpretation of field evidence necessary to describe the lake-cycle history. It also illustrates a relationship which is in conflict with published work. The units of Figure 2 are numbered and are referred to by number in the following discussion.

Unit i is eolian sand, still active under present conditions, with no evidence for soil development present. This sand correlates with the Fallon Formation eolian deposits of Morrison (1964, pp. 81, 84-85).

Unit 2 is interpreted to be lacustrine in origin, related to the latest recession of lake waters at an elevation of 4,122 feet in the Lahontan Basin. In the Carson Desert study, Morrison (1964, p. 81), recognized deposits related to several shallow lakes of Recent age, but all are below this elevation with the highest shoreline at 3,940 feet. This difference is an important divergnce in that the unit appears to extend to even higher elevations, perhaps around 4,200 feet. In work subsequent to Morrison (1964) he has not recognized such evidence (Porrison, 1964, personal communication). Following Morrison's terminology and definitions, this unit would be early Fallon in apparently immediately preceding in time the Fallon lakes recognized by him (Morrison, 1964, p. 81).

Unit 3 is a transgressive unit deposited in the early stages of the above-described lake cycle.

Unit 4 is a regressive unit with the Altithermal Soil slightly truncated by the previously-mentioned lake transgression. This soil is interpreted to be equivalent to the Toyeh Soil (Morrison, 1964, pp. 78-79) which developed, on the basis of C₁₄ determinations, between 4,000 and 6,000 years ago. This and the underlying lacustrine units corresponds by definition to the Sehoo Formation (Morrison, 1964, pp. 41-65).

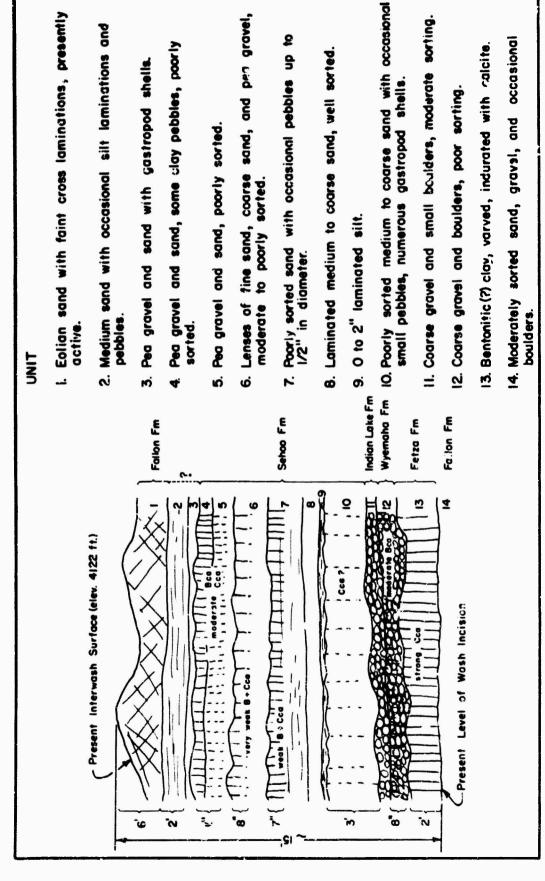
Unit 5 is a transgressive unit with slight cementation by calcite (C $_{\hbox{\scriptsize Ca}}$ horizon of the Toyeh Soil)

Unit 6 is a transgressive unit, with weakly-cemented grains. Presumably this cement is a C_{Ca} horizon in a truncated soil which developed upon a regressive unit now removed by erosion that was deposited on Unit 6. The regressive unit as well as the A, B, and part of the C_{Ca} soil horizon developed on it are inferred to have been removed by wave action of the lake which deposited Unit 5. The partial preservation of the C_{Ca} horizon is centative evidence for subaerial conditions between lake cycles.

Unit 7 is a regressive unit with a week truncated soil. The evidence of soil development indicates subaerial conditions, probably during mid-Sehoo time, at this elevation between lake cycles represented in part by Units 6 and 7.

Unit 8 represents part or all of the transgressive phase of the lake cycle during which the regressive Unit 7 was deposited.

Unit 9 may be interpreted to be an on-shore lagoonal silt deposit related to minor saud-bar development during the transgressive phase of the like



WASH BANK EXPOSURE OF LAHONTON VALLEY GROUP SEDIMENTS IN SW 1/4, SE 1/4 SEC. 15, T.17 N., R. 31 E., M. D. B. & M. OF FIG. 2 DIAGRAMMATIC SKETCH

Unit 10 may be a combination of transgressive and regressive lake deposits, or solely transgressive lake sediments. Here again occurs weak cementation by calcite indicative of a C_{Ca} horizon, where the A and B horizons of soil development have been removed by erosion. This unit is correlative with a part of Morrison's early Sehoo sediments.

Unit 11 is wash alluvium correlative with the lower tongue of the Indian Lakes Formation (Morrison, 1964, p. 68), the fluviatile equivalent of the early Sehoo sediments.

Unit 12 is wash alluvium correlative to the Wyemaha Formation (Morrison, 1964, p. 36). A moderately-developed soil on this alluvium is part of the sometimes composite geosol named the Churchill Soil (Morrison, 1964, pp. 38-41).

Unit 13 consists of slightly bentonitic deep-lake silts and clays probably correlative with the youngest deep-lake unit of the Eetza Formation. This unit is strongly cemented by a C_{Ca} horizon also related to the Churchill Soil. Some of the upper Fetza was removed by wash incision during the same interval of time that the soil development took place.

Unit 14 is present-day wash alluvium related to the present degree of incision by ephemeral wash erosion in nearly the same locality as that of exposed wash alluvium of Wyemaha age. This alluvium is correlative with the Fallon Formation (Morrison, 1964, p. 85).

The interpretation of the above exposure differs from Morrison's published findings in that a post-Altithermal Soil lake cycle exceeded the elevation of the exposure (4,122 feet) and at least three weak weathering profiles (prima facie evidence for subaerial conditions) instead of two occur in the Sehoo Formation. The possible existence of the young high lake has direct bearing on two phases of scientific endeavor, that of hydrologic studies in which relict flow systems may be present in low-permeability media adjacent to the Lake Lahontan basin, and that of archeologic studies of lakeshore occupational sites higher than the Fallon lake maximum described by Morrison. Low permeabilities and rates of movement comparable to those in the Sand Springs Range might permit the existence of relict groundwater mounds or ridges in ideal situations if a young prolonged high lake occurred less than 5,000 years ago. However, the evidence gathered in this study suggests that the ground-water ridge recognized in the Sand Springs Range is not such a feature. Many high shoreline occupational sites may not necessarily be Wisconsinan if this report's interpretations are correct. It is important to note that most investigations of Lake Lahontan history (Antevs, 1945, 1948, 1952; Morrison, 1961a, 1961b, 1964; Russell, 1885) have not recognized evidence for a very young high lake. Jones (1914, 1925, 1929) favored a young age for the entire lake deposit sequence, but this relationship is unsubstantiated ty more recent investigations. During the course of field work most of the units described and defined by Morrison in the Carson Desert study were clearly recognizable in one or more localities. However, the areal mapping of Morrison's units is difficult to perform with accuracy, and in many situations field criteria that enables the investigator to verify age relationships is lacking. The Eetza Formation was

only locally noted and relationships established by Morrison were not verified in this study.

Fourmile and Eightmile Flats

The geology of the valley fill in Fourmile and Eightmile Flats and contiguous areas is completed due to fluctuating Pleistocene takes which periodically occupied most of the alluviated terrain. In the adjacent Carson Desert to the northwest of Eightmile Flat, Morrison's detailed work, as well as the preceding section of this report, stand as guides to the complexity of unraveling the geologic history. Throughout most of the area included in this study on'y the relatively young Wisconsinan sediments are widely exposed, and even then only a very few exposures are present which display vertical relationships. Surficial deposits of the valley fill are predominantly of two types - subaerial and lacustrine. Most exposed deposits below 4,400 feet in elevation are related to Lake Lahontan lake cycles, and interbedded subaerial sediments related to the interpluvial periods of desiccation.

Surface Geology: The alluvium has been divided into six subdivisions based primarily upon mode of deposition and lithology. This differentiation of the alluvium differs from the detailed work of Morrison in that his subdivisions of the alluvium are based upon an additional criterion age.

Flanking much of the bedrock areas and extending well below the maximum shoreline of Lake Lahontan are dominantly coarse deposits of sand and gravel (gravel is used in this report to refer to coarse clastic material of predominantly pebble size, but containing particles that range from silt to boulders) deposited by the action of streams, lakes or a combination of the two. Primarily the stream action is that ci ephemeral distributary wash deposition on alluvial fans and the lake deposition is along the shoreline. It is known that lakes of Wisconsinan age and younger never exceeded approximately 4,380 feet in elevation, but it is often difficult to differentiate coarse subaerial fan alluvium from fan alluvium reworked by the lake below this elevation. Because of this difficulty the coarse and usually poorlysorted clastic material which ranges from large boulders to clay-size particles is designated Qflg in Figure 1. Shoreline symbols have been superimposed to indicate shoreline features. Usually the only firm criterion for differentiating between the two modes of deposition is shoreline depositional features visible on aerial photographs but often obscure in the field. Qflg deposits are composite in age, ranging from pre-Wisconsinan (Sangamon?) in areas above the maximum shoreline through Wisconsinan and Recent below the maximum shoreline.

The subaerial units are correlative with 1) Morrison's Paiute Formation of pre-Wisconsinan age, 2) an unnamed subaerial equivalent to the Eetza Formation of early Wisconsinan age, 3) the Wyemaha Formation of mid-Wisconsinan age, 4) the Indian Lakes Formation of late Wisconsinan age, and 5) the subaerial equivalent to the Fallon Formation of Recent age. The lacustrine units are correlative with Morrison's Eetza Formation of early Wisconsinan age, the Sehoo Formation of late Wisconsinan age, and the Fallon Formation of Recent age.

Closely related and somewhat similar in lithology to material mapped as Qflg, but occurring in more restricted environments of deposition is main

wash alluvium designated as Qsg in Figure 1. These deposits differ from the coarse fan deposits (Qflg) only in distribution and in lower silt and clay content. Most of the wash alluvium is of Recent Age a dequivalent to Morrison's Fallon Formation. Part of the material mappeas Qsg may have been reworked by a shallow Recent lake which left a faint strand line just south of the Fourmile Flat playa.

Occurring below 4,380 feet in elevation are lake sediments related to Wisconsinan and younger pluvial periods of inundation. These sediments, designated as Qlsg in Figure 1, are commonly well-stratified, sorted sands and gravels. Surface exposures are almost entirely restricted to sediments of the Sehoo Formation of late Wisconsinan age (post-Churchill soil and pre-Toyeh soil). Identifiable Eetza sediments of early Wisconsinan age (between the Cocoon and Churchill soils) are rare in this map unit except for a very narrow strip of sediments between the Sehoo maximum lake shoreline at approximately 4,370 feet altitude and the Eetza maximum lake shoreline at approximately 4,380 feet altitude. This map unit is commonly modified by shoreline features which are indicated in Figure 1.

Restricted more or less to within the playa margins of Fourmile and Eightmile Flats are lacustrine silt and clay deposits. These are believed to be predominantly equivalent to Morrison's Sehoo and Fallon Formations and are mostly deep-water clay deposits partly mantled by shallow-water silt and sand deposits. Capillary ground-water discharge marks the areal extent of these fine-grained deposits with a surficial frost of salts which accumulated between periods of precipitation.

In the lowest and central portion of Fourmile Flat a deposit of bedded saline evaporites is designated as Qle in Figure 1. Surface water accumulates in the lower part of the playa. This standing surface water, usually several inches in depth, but occasionally reaching several feet, evaporates and leaves behind increments of salt up to several inches thick. Mr. Huckaby, the operator of the salt mine on Fourmile Flat, reports that approximately the upper 30 feet of penetrated material is mostly bedded salt as interpreted from the log of a well drilled near the present operation. The surficial deposits are reported by him to be "over 99 percent pure sodium chloride". The high salt content is derived primarily from re-solution of the crust of salt which forms on Fourmile and Eightmile Flats when ground water discharged by capillary action and the surface water evaporates. The very low surface gradients for several miles surrounding the area of water accumulation permits the clastic increment carried by surface runoff to be deposited before or at the margin of the ponded water. It is reported that salt can be marvested by skimming the latest increment of crystallization from older, less pure salt beds, as often as once or twice a year, depending upon frequency and intensity of local precipitation.

Covering extensive areas within the topographic basin of Fourmile and Eightmile Flats are eclian sand deposits desagnated as Qes in Figure 1. These deposits are the most extensive and in pressure in the vicinity of Sand Mountain northeast of Fourmile Flat. The dune complex comprising Sand Mountain at times may be approximately 500 feet higher than the adjacent terrain (U.S.G.S. topographic map Carson Sink, Nevada, 1:250,000, 1907). The eclian sand deposits are localized by topographic configuration, usually a break or change in slope where inter- and intra-basin sand move-

ments produce concentrated deposits. The majority of the deposits are of composite age, ranging from mid-Wisconsinan, and perhaps even older, to Recent. Eolian deposits (Qes) are in places equivalent to Morrison's Wyemaha, Turupah, and the Fallon Formations which are respectively latest early Wisconsinan, late Wisconsinan, and Recent in age. Generally all eolian deposits except those of Recent age are slightly consolidated by weak cementation, and locally can be differentiated on the basin of associated soils. Most extensive deposits display evidence of deflation, inundation, and local reworking during various pluvial cycles and sporadic development of soil except for the presently active Fallon sand.

Structural deformation is not commonly recognizable throughout much of the area mapped in Fourmile and Eightmile Flats. However, a north-south structural grain is evident on aerial photographs and historic earth displacements along this general trend and subparallel to the Flat margins by been reported (Tocher, 1956). Most such features apparently are readly obscured by colian and fluvial processes. However, scarplets in thin alluvium and bedrock a few miles southeast of Fourmile Flat were observed. Elevation checks of the locally well-developed high shoreline of Lake Lahontan indicates that structural deformation of the bedrock basin margin is less than 10 feet where levels were run. Greater accuracy was not possible due to the difficulty of determining the exact position of the shoreline. In the more central portions of the alluvial basin relatively obscure small displacement faults have formed a graben which localizes the accumulation of surface water and salt. Most of the springs and seeps bordering Fourmile and Eightmile Flats probably occur along ruptures in the sediments. The faults mapped in the central part of the basin range from late Wisconsinan to Recent in age, and many occur in positions which suggest the possibility of compaction faults related to lithol ric variations.

Subsurface Geology: In Fourmile and Eightmile Flats subsurface data is meager. Total thickness of the valley fill is approximately 2,000 feet on the basis of geophysical data (see Part I of this report). Test wells H-2 and H-3 penetrated sediments similar to those of the Lahontan Valley Group described by Morrison (1964). At H-2 780 feet of interbedded lacustrine, eolian, and fluviatile sediments, similar to surficial deposits of Wisconsinan and Recent age, were encountered. It is important to note that the known maximum thickness of the Lahontan Valley Group are less than 300 feet where stratigraphic controls permit differentiation. The average thickness of the Lahontan Valley Group is probably less than 200 feet. Therefore, at H-2 it is probable that the lower 500 to 600 feet of penetrated sediments are pre-Wisconsinan sediments associated with pre-Lahontan Pleistocene pluvial and fluviatile cycles.

In K-3 310 feet of sediments similar to those encountered in H-2 were penetrated before granite was encountered. The portion of encountered sediments which represents the Lahontan Valley Group is unknown, but is probably represented by approximately the upper 100 feet of sediments.

In summary, the subsurface sediments to depths of at least 800 feet may be grossly similar to those at the surface, and the cyclic depositional conditions which occurred during the Wisconstant stage of the Pleistocene also apparently prevailed through much of earlier Pleistocene time. It is not known whether the full 2,000 feet of fill is similar in lithologic and

and hydrologic properties to that part penetrated by the test wells.

Fairview Valley

11

Surface Geology: In constructing a geologic map of Fairview Valley the alluvial fill has been subdivided into four units, primarily with differentiation based upon lithology. The western flank of the valley is an apron of coalesced fans, the exposed part of which is predominantly of Wisconsinan or younger age as suggested by the degree of soil development. The character of the fan deposits (designated as Qfgl in Figure 1) is predominantly coarse granitic sand, and lenticular gravel with minor silt and clay. This is apparently due to the dominance of granitic parent material and relatively steep ephemeral stream gradients. The soils noted near the surface and in barrow pits are all believed to be no older than mid-Wisconsinan and are tentatively correlated with Morrison's (1964) Churchill and younger soils of the Carson Desert studies. In very localized areas immediately adjacent to the bedrock of the Sand Springs Range several deposits of older alluvium are present. These local areas commonly display strong composite soil developments which are believed equivalent to Morrison's Cocoon Soil of probable Sangamon age. The several faults which extend from the frontal fault systems of the range into and displacing the alluvium are of probable post-Sangamon to Recent age on the basis of the soil correlations.

In the lower and more central portions of Fairview Valley better-sorted and sometimes coarser deposits of ephemeral stream alluvium occur in restricted channels. These deposits (Qsg in Figure 1) are generally post-Wisconsinan in age and are better sorted than fan deposits due to more frequent and vigorous water action. In the central part of the valley along the main ephemeral stream courses aggradation is the dominant process, whereas degradation is prevalent where the stream gradients are high near the basin margins. The deposits are distributed in dendrition patterns, whereas the ephemeral channels of the active fans form distributary patterns. Widening or spreading of main wash deposits has occurred in local areas due to structural damming. This relationship is best illustrated in the area one-half mile to the northwest of Frenchman Station. Here a fault cuts alluvium with the valleyward side relatively upthrown and the resultant low scarp dammed the alluvial material into a fan-shaped deposit before breaching occurred.

Most of the surficial deposits in Fairview Valley below approximately 4,180 feet in elevation are lake sediments (Qlu in Figure 1) which range from silt and clay in the lowest areas to reworked sand and gravel derived from fan alluvium at higher elevations. Numerous shoreline bar deposits of fine gravel and sand occur along the margins of the old lake between elevations of 4,165 to 4,177 feet. Commonly the highest bar deposit is well developed. Figure 3 is a diagrammatic cross section of the highest bar east of Frenchman Station where the age relationships of the deposits are best displayed. Where small washes have breached the bar there are exposures of a soil which appears similar in development to Morrison's Toyeh Soil (Altithermal Soil) in the Carson Desert. This tentative soil correlation would indicate that the last lake to reach this elevation is equivalent in time to the Lake Lahontan Sehoo pluvial period of late Wisconsinan age.

ш Relationships of the maximal bur near Highwoy 50 on the east slope of Foirview Volley. Soil is interpreted as altithermal on the basis of degree of development and would correlate with Morrison's (1964) Tayen soil. Lake which formed the bor therefore would be Sehoo in age (late Wisconsin). Silt and sand, no sall Very recent alluvium from ponding Poorly sorted sand and gravel fan alluvium Eolian sand, no soil Not exposed . Altithermal or Toyeh soil Eolian soil Not exposed ₹

FIGURE DIAGRAMMATIC CROSS-SECTION OF THE SHORE LINE BAR IN FAIRVIEW VALLEY

253

Tectopic effects such as faulting and verping bave a magnerably entitienced the shoreline position and features of the Falryiew Valley Plane come lake. In several localities shoreline bars (dasgrammatic in Figure 1) seem to be developed upon fault scarps in the alluvium. Along the northwaters highest shoreline of the lake an apparent offset occurs in the shoreline bar. This is interpreted to be the result of relative downthrow on the southwell side of a fault that moved during a pluvial period of shoreline bar development.

The east flank of Fairview Valley is mantled by an apron of coalesced fans of composite age (Qfgu in Figure 1), some of which are in various stages of destruction by erosion or burial, and others which are actively growing. In many, the lower portion of the fan is presently an environment of deposition, whereas the same fan nearer to the bedrock contact is presently undergoing dissection. This relationship is perhaps a result of tectonic activity along the alluvium-bedrock margin flanking the Fairview Peak bedrock mass. In gross aspect the surficial material of the fans along the east side of Fairview Valley has a higher percentage of silt and clay when compared to the fans flanking the west side of the valley. Also, the older deposits exposed on the east side of the valley typically display deep, well-developed weathering profiles consisting of strong composite geosols. On a comparative basis with imperfectly dated soils in other localities of western Nevada where soil stratigraphy and Lake Lahontan sediments provide stratigraphic control, some of the weathering profiles along the east side of Fairview Valley appear to be as old as Yarmouth, and could be even older. Nearly all of these pre-Wisconsinan fan-surface remnants occur on the upper half of the fan as high inter-wash remnants. Also, the number of faults involving the fan alluvium is much greater where the older deposits are exposed at the surface. This relationship suggests two possible interpretations regarding the location of the tectonically-induced deformation: 1) The zone adjacent to the bedrockalluvial contact has been more active than the more valleyward part of the basin; 2) The older deposits, the greater the length of time for faults to have occurred, and therefore the greater density of faults in the upper half of the fan apron on the east side of Fairview Valley is a direct function of the age of the deposits. The evidence is not conclusively in favor of either of the two possible interpretations. However, faint lineations as seen on aerial photographs as well as occasional linear protrusions of old alluvium the oughout Fairview Valley indicate the fault displacements have occurred throughout much of Fairview Valley and the density of faults may vary with the age of the deposits.

Most of the west and east margins of the valley are fault contacts, or probable fault contacts obscured by deposition or erosion. The eastern Sand Springs Range front trends in a north-south direction and is formed by fault segments which trend in northeasterly or northwesterly directions. Along this fault margin of the range active aggradation of the fans has been the dominant process during late Pleistocene and Recent time. On the east side of Fairview Valley the valley margin faults are subparallel and grossly linear in a slightly east of north direction. Here geomorphic relationships suggest reverse movement during middle or late Pleistocene time along some segments of the faults which places alluvium and bedrock in contact. This relationship is suggested by the remnants of old fan surfaces occurring up to 50 feet higher in elevation than the bedrock in immediate fault contact to the east, and the way that present drainage bypasses the old ian rem-

The course. Figure 4 illustrates the gross relationships of the east-west valley copographic profile and marginal fault relationships.

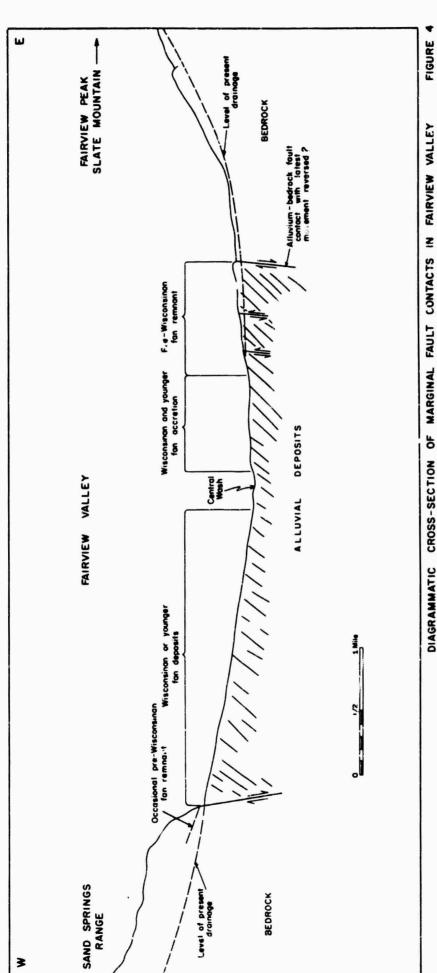
The structural grain within the northern half of Fairview Valley trends northeasterly because of faults and tectonically-controlled sediment distribution whereas the gross trends of the valley and bounding ranges are more northerly. These local differences in trend appear to result from small displacement faults and related tilts that are partly buried or obscured by younger deposits along trends which continue from or are subparallel to frontal fault segments along the east side of the Sand Springs Range. In the south half of Fairview Valley there is little to suggest that similar local structural trends cross the valley. Here such features producing the northeast grain are either absent or completely buried by alluvium.

South of Fourmile Flat and west of the southern portion of Fairview Valley in the vicinity of the ghost town of Rawhide an extensive area of alluvium occurs. This area was not studied in detail because of its relative unimportance to the objectives of this study, but was mapped by aerial photography methods. Reconnaissance of the Rawhide area indicates that most of the alluvium mapped as Qfgu in Figure 1 is of pre-Wisconsinan age on the basis of soil developments. Much of the alluvium is similar to that flanking the east side of Fairview Valley, where young alluvium partly obscures the older deposits and associated faults. Eolian deposits mapped as Qes are similar in age and character to those found in Fourmile and Eightmile Flats.

Subsurface Geology: Fairview Valley is a structural bedrock basin which has been partly filled with alluvial sediments. Gravity studies indicate that consolidated rocks are at least 4,800 feet deep in the southwest portion of the valley, in the vicinity of Test Holes HS-1 and H-4. The surface of these consolidated rocks, as indicated by gravity profiles, slopes upward to the east and to the north so that the depth to bedrock near the east side of the valley is about 4,000 feet and near the center of the valley along U. S. Highway 50 about 5,500 feet. Geophysical studies have not been made farther north in the valley but geomorphic interpretation suggests that the bedrock may be shallower in that direction.

Detailed information of the subsurface geology is limited to local areas around Frenchman Station and HS-1 and H-4, where wells have been drilled and logged. Driller's logs are available at Water Points 17 and 18 at Frenchman Station for wells that have penetrated 288 feet into the valley fill. The log of the well at Water Point 18 is given below. It suggests alternating lacustrine and fluviatile sediments, as might be expected of sediments along the margin of Labou Flat if depositional conditions in the past have alternated between lacustrine and fluviatile cycles similar to those evidenced in surficial deposits.

FROM FEET	TO FEET	THICKNESS FEET	TYPE OF MATERIAL
0	30	30	Silt and sand
30	42	12	Clay
42	55	13	Sand and gravel



DIAGRAMMATIC CROSS-SECTION OF MARGINAL FAULT CONTACTS IN FAIRVIEW VALLEY

FROM FEET	TO FEET	THICKNESS FEET	TYPE OF MATERIAL
55	144	89	Sand and gravel
144	148	4	Coarse gravel
148	170	22	White clay
170	223	53	Sandstone
223	283	60	Sand and silt with thin gravel layers - water encountered at 227 feet.
283	288	5	White clay

The log of a former well beneath the playa deposits of Labou Flat in the Bernard Navy Bombing Range south of Frenchman Station, reports essentially all "clay" (silt or silty clay?) to a depth of 400 feet. This log indicates that playa or lacustrine depositional environments have prevailed over an extensive period of time. At HS-1 and H-4 the lithologic logs (see Appendix C and F) indicate that to a depth of 813 feet the character of the alluvial fill is similar to that in surface exposures in the same general area. The 813- to 935-foot interval of penetrated material is not as coarse as the above material and appears to be related to a lower-energy environment.

In summary, the limited subsurface lithologic data in Fairview Valley suggests that the character of the alluvium does not differ greatly from that near the surface in various depositional environments to perhaps a depth of around 800 feet. At greater depths it is probable that the unconsolidated or semiconsolidated alluvium generally decreases in permeability and storage capacity with depth, and thus becomes less favorable aquifer material.

SUPPLEMENT ON THE OCCURRENCE OF GROUND WATER

During the course of hydrologic studies all known water points and test holes were observed, tested, or sampled to obtain hydrologic information. In the 900 square miles of terrain considered, there is approximately one data collection point (a spring, seep, well, or surface water sample station) for every 14 square miles of area. In reality, most of the data is localized, with most of the opportunities for collection occurring in local groupings rather than being spread evenly through the region. Table 1 lists the water points which include springs, seeps, and wells not constructed or developed for this study, as well as the hydrologic test holes. Figure 5 is an index map of the water points.

Springs and Seeps

Within a 25-mile radius of the test site a number of springs and seeps were visited, most of which have been developed for stock use. The general geographic locations, discharge if obtainable, geologic environment, and quality of water are herein described. Undoubtedly a few natural discharge

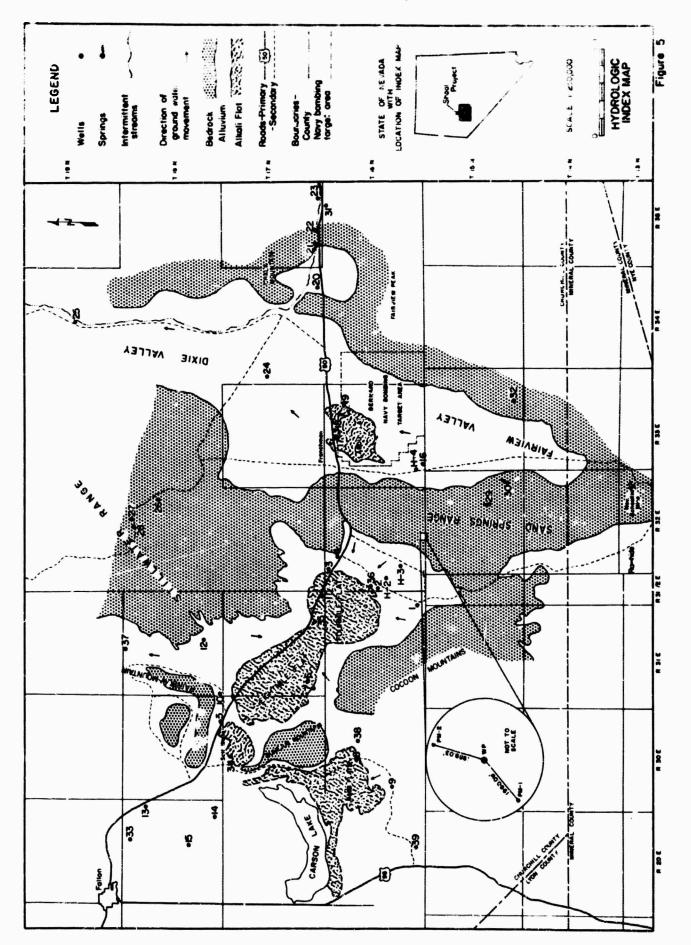


TABLE 1. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

	HEMA RKS	Water supply well for project	Water-level recorder on well	Water-level recorder on well	Water-level recorder on well		Flowing well	Flowing well	By old tungeren mill	Big Top Restaurint	Flowing well	Flowing well
AVER DEPTH	TO WATER	300	111	326	299	285	† † †	!	99	29	!	ļ
DT S CHA BCE	GPM (est.)	70	99	5-10	70	5-10	50-55	0.75	į	20-25	0.25-1	1-1.5
חשאת	IN FEET	669	768	480	935	315	- t - t	27	162	;	! !	· !
	USE	Test Well	Test Well	Test Well	Test Well	Stock	Stock	Stock	Aband.	Dom. and Commer.	Stock	Stock
OUNER	OR LESSEE	A.E.C.	A.E.C.	A.E.C.	A.E.C.	Dr. C. P. McCuskey	Dr. C. P. McCuskey	Dr. C. P. McCuskey	F. Bennett	B. Matthews	Whitman	Whitman
	LOCATIONS	SWŁ SWŁ NWŁ Sec. 32 T15N R33E	SEŁ Sec. 19 T16N R32E	SWŁ SEŁ NEŁ Sec. 29 T16N R32E	SWŁ SWŁ NWŁ Sec. 32 T16N R33E	SEŁ NEŁ SWŁ Sec. 36 IIÓN R3IE	NW% Sec. 19 T16N R32E	SEŁ SWŁ NWŁ Sec. 5 Ilón R32E	NWŁ SEŁ SEŁ Sec. 5 II6N R32E	SFŁ SEŁ SWŁ Sec. 35 T18N R30E	NWŁ NWŁ NEŁ Sec. 31 TI7N R31E	SWŁ NEŁ NWŁ Sec. 31 TI7N R31E
	DESIGNATION	HS 1	н-2	H-3	7-Н	W. P. 1	W. P. 2	W, P. 3	E. F. 4	W. P. 5	W. P. 6	W. P. 7

CONT. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA TABLE 1.

REMARKS		Sealed well		Flowing well			Flowing well	Flowing well	Leasee - Stark	Frenchman Station	Frenchman Station
AVER. DEPTH TO WATER	22	;	32	ļ	300	ļ	į	1 1	319	224	223
DISCHARGE GPM (est.)	1-2	10-15	0.5-1	1	0.5-1	3-5	0.5-1	1-2	ν,	15	17
DEPTH IN FEET	;	;	300	190	350	14	80	; ;	364	280	288
USE	Stock	Stock	Stock	Aband.	Stock	Domes.	Stock	Domes.	Stock	Domes.	Domes.
OWNER	R. Bass	R. Bass	 	 1 1 1	3 3 3 6 9	H. Pierce	P. Schaffer	S. Flippen	B.L.M.	Weyher	Weyher
LOCATIONS	SW% Sec. 9 T16N R30E	SW% Sec. 20 T16N R30E	SWŁ SWŁ SWŁ Sec. 31 I18N R31E	NW% Sec. 6 T16N R32E	SW½ Sec. 27 T18N R31E	SE% Sec. 12 T18N R29E	NE½ Sec. 35 T18N R29E	Swł Sec. 22 T18N R29E	SEŁ SEŁ SWŁ Sec. 32 TIÓN R33E	SWŁ SEŁ NWŁ Sec. 3 T16N R33E	SWł SEł NWł Sec. 3 T16N R33E
DESIGNATION	W. P. 8	W. P. 9	W. P. 10	W. P. 11	W. P. 12	W. P. 13	W. P. 14	W. P. 15	W. P. 16	W. P. 17	W. P. 18

TABLE 1. CONT. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

REMARKS	Leasee - Stark		01d 3-C Camp	Westgate	Ranch at Middlegate	Leasee - Stark	Leasee - Stark	Bulldczed sump			Frenchman Spring
AVER. DEPTH TO WATER	219	266	65	35	93	303	279	!!	16	07	i
DISCHARGE GPM (est.)	7.	!	! !	10	1000	10	2	i	10	10	! !
DEPTH IN PEET	373	365	110	51	202	334	325	09	80	120	-
USE	Stock	Aband.	Aband.	Stock	Dom. and Irriga.	Stock	Stock	Stock	Stock	Stock	Stock
OWNER OR LESSEE	B.L.M.	State	State	B.L.M.	Weyher	B.L.M.	B.L.M.	Kent	Kent	Kent	B.L.M.
LOCATIONS	NEŁ NWŁ NEŁ Sec. 11 T16N R3JE	SE½ Sec. 35 T17N R34E	SEŁ Sec. 32 T17N R35E	SW% Sec. 33 T17N R35E	NEŁ SEŁ Sec. 34 Ilin R35E	SW\ Sec. 18 I17N R34E	NEŁ Sec. 21 T19N R34E	NW\$ Sec. 13 T18N R32E	SW% Sec. 1 :18N R32E	SE½ Sec. 3 T18N R32E	SW% Sec. 23 T15N R32E
DESIGNATION	W. P. 19	W. P. 20	W. P. 21	W. P. 22	W. P. 23	W. P. 24	W. P. 25	W. P. 26	tr. P. 27	W. P. 28	W. P. 29

TABLE 1. CONT. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

REMARKS	Seep	Middlegate	Slate Mountain Spring		Augered hole for observation	Augered hole, now caved	Augered hole, now caved	Leasee - Kent	Abandoned Well	Lee and Allen Hot Springs	Mt. Lincoln Springs
AVER. DEPTH TO WATER	!	98		ဆ	7	Flowing	Flowing	126	79	Surface	Surface
DISCHARGE GPM (est.)	Negligible	ł	;	;	;	0.25	0,25-1	;	!	Over 50	30-50
DEPTH IN FEET	Land	;	}	20	42	52	52	130	;	ł	1 1
USE	Aband.	Domes.	Stock	Dom. and Irriga.	Obser. Well	Obser. Well	Obser. Well	Stock	Stock	Dom. and Irri.	Stock
OWNER OR LESSEE	B.L.M.	Malendy	B.L.M.	F. Soars	A.E.C.	A.E.C.	A.E.C.	B.L.M.	;	;	;
LOCATIONS	NW% Sec. 36 T15N R32E	NWŁ NEŁ NWŁ Sec. 3 Ilón R35E	SEŁ NWŁ Sec. 35 T15N R33E	NEŁ Sec. 3 T18N R29E	NEŻ NEŻ NEŻ Sec. 32 T18N R30E	NW\ Sec. 34 T17N R31E	NW% Sec. 19 T16N R32E	NEŁ Sec. 4 T18N K31E	S\foresign	NEŁ Sec. 34 T16N R29E	SWŁ Sec. 1 TI9N R13E
DESIGNATION	W. P. 30	W. P. 31	W. P. 32	W. P. 33	W. P. 34	¥. P. 35	W. P. 36	W. P. 37	W. P. 38	W. P. 39	s. F. 40

TABLE 1. CONT. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

REMARKS	Dixie Valley - Abandoned well	Dixie Valley - Abandoned well	Dixie Valley - Abandoned well	Dixie Valley	Dixie Valley	Dixie Valley Abandoned well	Dixie Valley (two wells)
AVER. DEPTH TO WATER	7	22	30	35	39	'n	19 & 37
DISCHARGE GPM (est.)	1 1 1	į	!	ļ	ļ	ļ) ! !
DEPTH IN FEET	;	• • •	;	}	;	•	;
USE	Obser.	Obser.	Obser.	Dom and Stock	Irr. and Stock	Obser.	Dom. and Irr.
OWNER OR LESSEE	ţ	ļ	;	Stark	Stark	ļ	\$ •
	54	54	12			54	
LOCATIONS	SUZ NWZ Sec. 24 T21N R34E	SWŁ NWŁ Sec. 24 T21N R34E	SEŁ SWŁ Sec. 27 T21N R34£	SW Sec. 35 TZIN R34E	SW% Sec. 35 T21N R34E	NWŁ SWŁ Sec. 24 T21N R34E	SWk Sec. 25 T21N R34E
DESIGNATION	DV 1	DV 2	DV 3	DV 4	DV 5	DV 6	; AQ

points were not located and visited due to inaccessibility and remote locations.

Water Point 3: Sand Spring occurs on the southeast margin of Fourmile Flat a few hundred yards north of U. S. Highway 50, in the SE% SW% NW% of Section 5, Township 16 North, Range 32 East. This discharge point is now a developed flowing well with a discharge of approximately 0.75 gallons per minute. However, due to the name "Sand Spring", and a history as a watering point in the early development of the region, Water Point 3 may have been initially a spring or seep. It now consists of a flowing well with a gravity feed to a stock-watering tank. Approximately one-half mile to the northwest, at the ruins of an old freight station, several dug wells also contain ground water. These were not monitored.

This flowing well is at the geologic boundary of sand dunes and the fine-grained material of Fourmile Flat. The sand dunes overlie extensions of alluvial fans from the nearby hills. The localization of discharge in this zone may be due to a fault or weal ess zone in the sediments, though no clearly defined fault can be differentiated from the strand lines of Lake Lahontan. Typically the ground water at depth in discharge areas has a higher potential than at or near the surface, giving an upward gradient. For ever, throughout much of Fourmile and Eightmile Flats the upward-circular a ground water is retarded by fine-grained sediments so that evaporation as water occurs before it reaches a surface in large and quantities to form standing water. Flowing springs or seeps commonly indicate some break in the fine-grained confining sediments. The water at W. P. 3 is high in dissolved solids, but not nearly as poor in quality as many of the discharge points of Fourmile and Eightmile Flats.

Water Points 6 and 7: Rock Springs are located on the west margin of Eightmile Flat, about 10 miles northwest of the test site; W. P. 6 is in the NW社 NW社 NE社 of Section 31, Township 17 North, Range 31 East; W. P. 7 is in the SW NE NW of Section 31, Township 17 North, Range 31 East. These two water points are developed seeps occurring along the margin of Eightmile Flat. In the immediate vicinity of W. P. 6 are several undeveloped seeps and associated vegetation mounds. The developed seeps consist of shallow flowing wells and gravity-fed stock-watering tanks. The discharge of W. P. 6 is approximately 0.25 gallons per minute; W. P. 7 is approximately 1.0 gallons per minute. The geologic environment is similar to that of Water Point 3, with discharge occurring through probable weakness zones in the sediments. Water Point 7 is located on the trace of a well-defined westnorthwest fault; W. P. 6 and the adjacent seeps form a linear pattern which is in line with a northwest fault lineation visible on air photos to the southeast of the water point. The poor quality of water (see Appendix G) from these springs is typical of waters in Fourmile and Eightmile Flats.

Water Point 29: Frenchman well is approximately five miles south of the test site, in the SWz of Section 23, Township 15 North, Range 32 East. It occurs near the head of a steep ravine as a dug well in jointed granitic bedrock. This water point had served as a siphon feed to stock-watering troughs, now abandoned. At the present time, standing water occurs in an old-timbered re-enforced dug well approximately 10 feet in depth. The material penetrated was apparently entirely granitic alluvium which sporadically occupies the ravine bottom. Discharge is unmeasurable, but is

predominately from evaporation. The source of water may be perched ground water in a local joint system in the granite, therefore the seep discharge would be primarily controlled by the amount of recharge from precipitation within an unknown but probably short period of time.

Water Point 30: Chukar Seep is approximately six miles south and slightly east of the test site, in the NW2 of Section 36, Township 15 North, Range 32 East. The seep occurs in a ravine bottom issuing from alluvium with discharge too small to measure. The geologic environment is that of jointed granite overlain by several feet of wash alluvium. Two hydrogeologic situations may give rise to this seep: 1) a bedrock irregularity under the alluvium may form a dam, ponding the ground water carried by the alluvium after surface runoff occurs in the wash; or 2) the water issues from fractures in the granite underlying the alluvium, thereby saturating the alluvium. In the former case, the water is perched and does not represent the regional water table; in the latter case, the water may or may not be perched. The depths to water table encountered in test holes in both the bedrock and valley fill suggest that the water at Chukar Seep is perched.

Water Points 29 and 30 are the nearest granite terrain points of natural discharge to the detonation point. Evidence indicates that both points of discharge are up-gradient from the ground water associated with the detonation, regardless of whether the ground water being discharged is perched or part of the regional system. This relationship is indicated by the comparison of the elevations of the discharge points, with W. P. 29 at approximately 5,400 feet of elevation, W. P. 30 at approximately 5,000 feet of elevation, and the highest potential of ground water in the vicinity of the detonation at 4,600 feet in elevation. Shot-induced water-level changes adjacent to the detonation are not of the magnitude or extent to reverse the regional configuration.

Water Point 32: Slate Mountain seep is approximately ten miles southeast of the test site on the western flank of the Fairview Peak-Slate Mountain Range. It is in the SE% NW% of Section 35, Township North, Range 33 East. This seep occurs in wash alluvium shallowly underlain by granite with a bedrock fault occurring some 50 feet westward. The discharge is unmeasurable and standing water occurs only upon trenching. The hydrogeologic environment could either be a subsurface bedrock dam with perched water similar to the situation in case #1 at Chukar Seep, or deeply-circulating water related to the fault. Indirect evidence favors the former control as phreatophytes occur for considerable distance up the wash from the seep.

Water Point 40: Mt. Lincoln Spring is approximately 25 miles north and slightly east of the test site on the east flank of the Stillwater Range in the SW% of Section 1, Township 19 North, Range 33 East. It consists of several localized seepage areas on the flank of a sharply-incised valley and periodically forms six rivulets or more on the side of the valley wall. The discharge appears to fluctuate on an annual basis. The seeps occur from the crest of a narrow, sloping ridge over a lateral distance of approximately 100 yards along the same contour, some 200 feet above the valley floor. This is a unique position for springs in this semi-arid area. The October, 1964 combined discharge estimated from measurement of one rivulet is 30 to 50 gallons per minute. The geologic environment is a fault or shear zone that subparallels the ridge, involving a dense intermediate

volcanic rock. Although exposures are poor, float indicates the seeps originate in brecciated and partly mylonized volcanic rock. Volume of discharge suggests this spring is a discharge point of the regional water system, and not the result of perched water derived from precipitation recharge in the immediate area.

Salt Farm 1. 2, 3: (not included in inventory table, but these points have been sampled for analysis). These water points occur on the salt flat of Fourmile Flat a few miles west of the test site. They are openings in the salt crust of less than a foot in diameter to several feet in diameter in which the water stands very near the level of the uppermost salt crystallization surface. Discharge from these seeps is from evaporation. According to Mr. E. Huckaby, the operator of the nearby salt farm, the seeps were first noted the summer of 1955 after the two major earthquakes the previous year. These seeps therefore may be related to weakness zones in the sediments underlying the salt deposits. The high concentration of dissolved solids in the discharged water perhaps is due to solution of salts from the Lake Lahontan sediments through which the water passes or to the re-solution of the salt deposits or to a combination of both processes.

In summary, the occurrence of springs and seeps is not restricted to the regional discharge zones, such as Fourmile Flat and Dixie Valley, but also occur as infrequent local discharge points within the regional recharge zones, such as the upland area of the Sand Springs Range. These points of discharge in the regional recharge area appear to be related to local situations of relatively high permeability material up-gradient from low permeability material. The depth to and the configuration of the regional water table determined by the test-hole program provides indirect evidence that most points of spring and seep activity within the recharge zones probably result from perched water. In all instances of these natural discharge points the water is either perched and thus up-gradient from ground water in the regional system adjacent to the detonation, or of such distance from the test site as to be completely removed from the potentially contaminated portion of the system.

Hydrologic Tests in the Vicinity of Ground-Zero

Knowledge of the occurrence of ground water in the Sand Springs Range, as reported in Part I of this report, was incomplete, with virtually all of the information on the bedrock hydrology of the region obtained from a few springs and seeps and from test hole ECH-D. Due to the rotary drilling methods employed in the construction of ECH-D and the absence of ground-water discharge points in the general area of the test site, little information could be obtained concerning movement of water in the saturated zone of the test site. Since Part 1 of this report was completed, information from five additional drill holes (PM-1, PM-2, PM-3, PM-8, and USBM #1) in the test site vicinity has been obtained. This part of the report is concerned with this information and reviews the result of previous drilling.

ECH-D: Hydrologic tests were conducted between July 13 and 21, and August 1 to 4, 1962, on test hole ECH-D (ground-level elevation 5,233 feet) at the Shoal Test Site. The water level, as determined during and after several tests ending on July 21, 1962 (see Figure 17 in Part I), consistently returned to elevations of approximately 4,265 feet (approximately 968 feet

from ground surface). Further tests conducted with a packer indicated that water was entering the hole at horizons above 4,061 feet (1,172 feet of depth) in small quantities, and that it entered the hole in larger quantities below an elevation 4,014 (1,219 feet). It is estimated that 80 to 90 percent of the water entered between 4,014 feet (1,219 feet) and the bottom of the hole at an elevation 3,878 feet (1,355 feet), and that over half of the water entered below elevation 3,951 feet (1,282 feet). In other words, all fractures below elevation 4,265 feet (968 feet) were saturated and yielded water to some extent, but the fractures near the bottom of the hole as of July 21, 1962 (elevation 3,878 feet) transmitted more water.

During the period July 21 to August 1, 1962, test hole ECH-D was deepened an additional 220 feet to the elevation 3,658 (1,575 feet of depth). At elevation 3,794 (1,439 feet) a fault was encountered dipping approximately 70° S., and probably striking east. The width of the fault zone is at least 75 feet.

On August 1, 1962, another recovery test was conducted, the results of which are shown in Figure 17 in Part I of this report. The recovery rate appears similar to the earlier tests, but in approximately the same period the water level returned to elevation 4,147 feet (1,086 feet), a head loss of 118 feet when compared to previous recoveries. This suggests that the ground-water potential decreases with depth, a phenomenon characteristic of recharge areas. However, after prolonged recovery of 86 days, the water level had reached an elevation of 4,275 feet (958 feet) which is higher by approximately 10 feet than the recovery of earlier tests when the hole was not as deep. It is probable that water injected during construction affected this recovery. Unfortunately, due to drilling operations, prolonged recoveries at the 3,878-foot hole depth could not be made.

A total of 386,000 gallons of water were used in drilling ECH-A which at one point passes within 150 feet of ECH-D. An undetermined but relatively small fraction was circulated to the surface. Circulation was lost almost consistently from the surface to approximately an elevation of 4,580 feet. The largest circulation loss was at approximately an elevation of 4,580 feet, the position of a major shattered zone within the granite. Complete loss of circulation generally occurred as drilling proceeded through the major fault zones above the 4,950-foot elevations. The hole (ECH-A) was then cased to the entire depth. At a later date the hole was uncased, drilled to an elevation of 4,140 feet, and recased. Circulation was never completely lost during the second phase of drilling.

Because ECH-A and ECH-D approach to within approximately 150 feet of each other, and considering the fractured granite, it is possible that some hydraulic communication exists between the two drill holes. This is not to imply that there is necessarily a single direct system of fractures between the two holes. During testing of ECH-D, 4,000 galions of water were introduced into ECH-A in an effort to determine any communications between the holes. Nothing conclusive was determined from the test.

During the drilling of ECH-D, 191,000 gallons of water were used, of which an undetermined amount was circulated to the surface. It is highly probable that the use of air under high pressure during drilling operations forced some water back into fractures in the granite walls of the hole.

However, it is known that some of the introduced water returned to the surface.

PM-1: The PM holes were drilled so that instruments could be installed to observe the Shoal Test. As each PM hole was completed the drilling muds were flushed out as much as possible in preparation for bail tests. Bail tests were necessary as depths to water and the low-yield medium precluded economical use of pumps. The bailer used for these tests was of a dart type and capable of holding approximately 35 gallons of water. Each hole was bailed below an estimated static level which was determined from previous observations on the ECH-D hole; the hole was then allowed to recover to a static level and the recovery curve was plotted. This initial static level was required in attempts to estimate residual drawdowns on the final recovery test. Each hole was bailed in a controlled test taking out 35 gallons of water at equal time intervals. Recovery in the bailed holes allowed a rough estimate of the coefficient of transmissibility of the granite in the vicinity of Ground-Zero by methods outlined in Part 1 of this report.

Bailing operations commenced on instrument hole PM-1 on March 22, 1963, and continued until the water level was lowered to approximately 1,120 feet below the ground level. At that time, the recovery of the water level was observed with frequent measurements until a static level of 1078.9 feet was obtained below the measuring point established for the hydrologic tests (elevation of this m.p. is 5,368.8 feet and ground-level elevation at PM-1 is 5,358.03 feet). A Fisher M-Scope was utilized for water-level measurements. On March 24, a controlled bail test commenced taking out 35 gallons of water every eight minutes. The last bail was lifted with the water level approximately 1,150 feet below the measuring point and recovery of the water level was again observed. After 24 hours the recovery curve had flattened out at 1,100.5 feet below the measuring point (at 1,089.63 feet below the ground level).

Since the 1,089.3 (ground-level reference) level reached by the water in PM-1 on March 25, 1963, the level dropped gradually to a static position of 1,094.9 fect below ground level April 29, 1963. This approximate level was continually observed until time of instrumentation of this hole.

Graphs of the initial recovery curve and the recovery curve from the controlled test are given in Figure 6.

PM-2: Testing on instrument hole PM-2 was conducted in the same manner starting on April 9, 1963. The water level, after the initial bailing, was over 1,183 feet below the measuring point (5,328.77 feet in elevation). The ground level at this point is 5,318 feet in elevation. However, the water level in the hole did not fully recover from this operation after 48 hours of observation. Due to requirements of the drilling rig elsewhere, there was insufficient time to allow full recovery and controlled bailing. Figure 7 shows the rate of recovery for PM-2 based on this initial test.

Water levels continued to rise in this hole to 715.8 feet below ground surface on April 24, 1963. The water level then dropped consistently and was still dropping when the hole was instrumented.

PM-3: After initial bailing on PM-3, on April 22, 1963, the water level

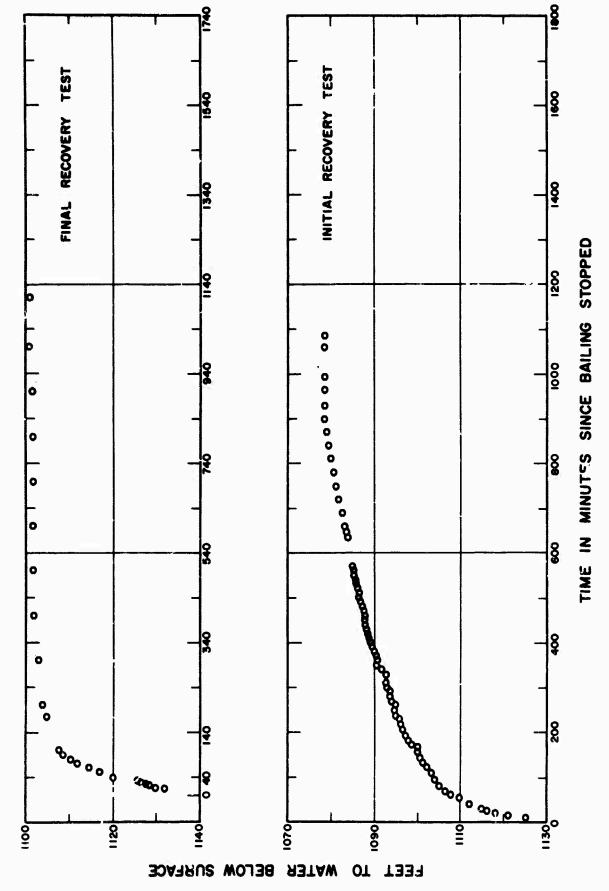
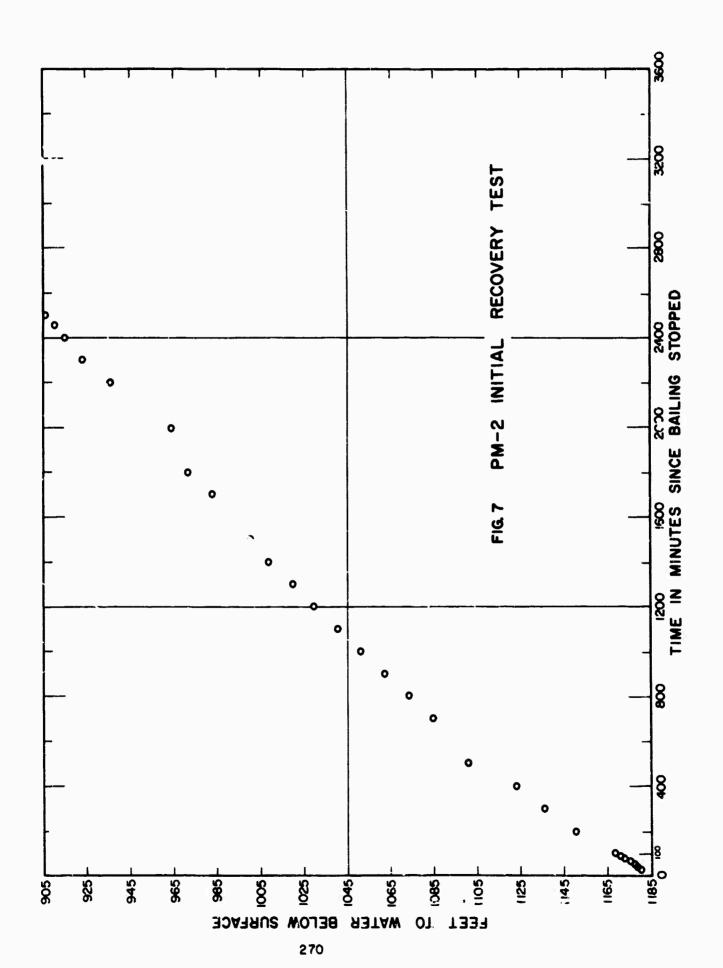


FIG. 6 PM-I RECOVERY TESTS



was more than 1,050 feet below the measuring point established for testing. This measuring point was 5,130.1 feet elevation and the ground level elevation at PM-3 is the same. Within 30 hours the water had leveled off at 1,038.0 feet below the measuring point. A controlled bailing test was conducted until the water was 1,092.7 feet below the measuring point. Recovery of the water level was observed for 24 hours at which time the water was at a depth of 1,077.0 feet below the measuring point. The water level continued to rise gradually and depth to water was measured at 1,054.0 feet below ground surface on April 29, 1963. The water level then gradually declined to a depth of 1,070.95 feet below the ground level on July 25, 1963, the last opportunity for measurement.

Figure 8 depicts the initial and controlled recovery curves for PM-3.

PM-8: Hydrologic testing on FM-8 was limited to monitoring recovery of water to a static level after the water level was lowered by bailing. The water level stood above the normal static level for ECH-D for a considerable period of time. Drilling fluids may have influenced reading, however, the difference in hole depths and probability of decreasing potential with depth make this relationship expectable.

U. S. Bureau of Mines Test Hole 1: After initial bailing on this hole the water level was at a depth of approximately 1,128 feet below the measuring point established for the tests. Elevation of this measuring point was 5,212 feet and ground-level elevation is approximately 5,200.8 feet. Recovery of the water level was observed until a relative static level was reached at a depth of 907 feet below the measuring point. A controlled bailing test was then conducted.

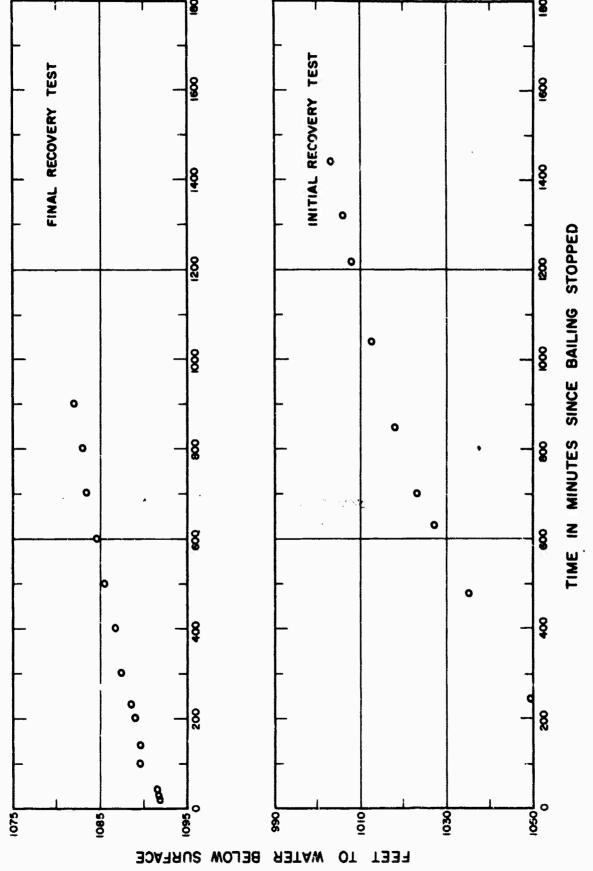
On the basis of the initial recovery curve a major fracture zone was predicted at a depth of 910 to 920 feet below the ground surface. This recovery curve shows a noticeable flattening at this interval due to a longer time required to fill the voids associated with the fracture zone. Subsequent logging verified this prediction.

Figures 9 and 10 depict the initial and controlled recovery curves.

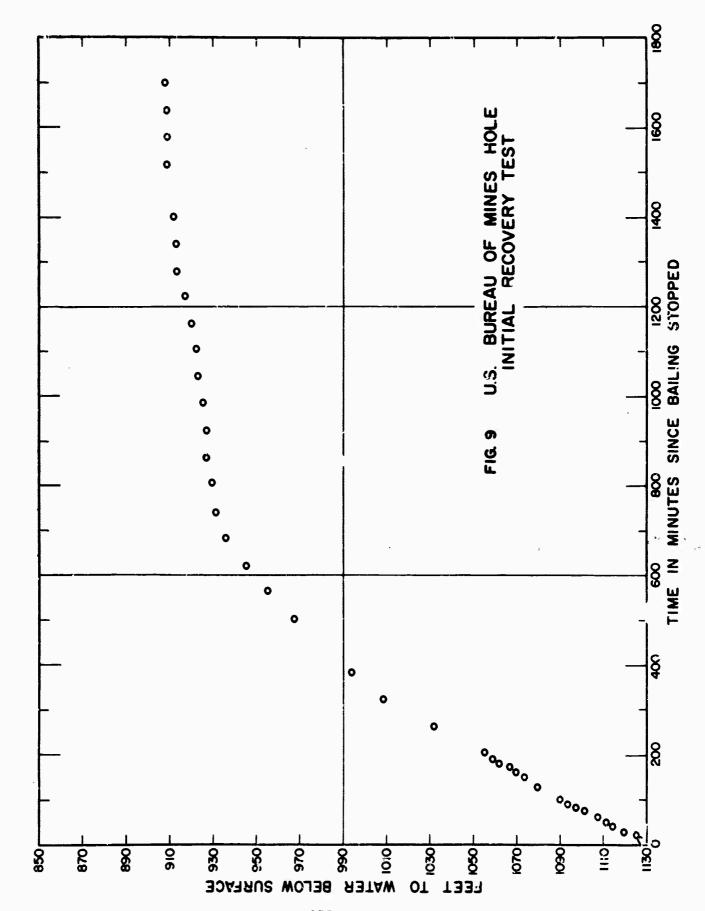
Interpretation and Conclusion

The data presented in this section is more meaningful if analyzed on a semi-quantitative basis. The natural conditions in the granite of the Sand Springs Range bear little resemblance to the idealized mathematical model present in Part I of this report and, therefore, values of aquifer characteristics are unreliable. Practically every assumption upon which the rodels are based are violated, a fact well demonstrated by the peculiar shape of the recovery curves. For example, when plotted on semi-logarithmic paper used in the accepted method the final recovery curve of the water level in PM-1 exhibited two inflection points and three slopes. Values of the transmissive constant (T) as determined from each slope ranges from 28 to 77 gallons per day per foot. The recovery curve for PM-3 also exhibits several slopes with the values of the transmissive constant ranging from 19 to 963 gallons per day per foot. The upper limit is unquestionably out of the realm of possibility. The recovery curve for water levels in the USBM #1 similarly exhibits several slopes with values ranging from 61 to 174 gallons per day per foot. The extremely slow rate of recovery and the fact that





IG 8 PM-3 RECOVERY TESTS



Bang.

the water level in the test holes, where several hundred feet of saturation occur, could be rapidly drawn down at a pump ng rate of approximately 5 gallons per minute conclusively points to the low transmissive capacity of the fractured granite. The tests indicate that a range of conditions exists from test hole to test hole, but in general the transmissive capacity of the granite in the test site area appears lower than that encountered in H-3 (see the test results in Part I of this report). This is well demonstrated by: 1) the PM-2 test, where water levels were still recovering rapidly 48 hours after bailing, and 2) by the prolonged lengths of time necessary for static levels to be reached in the other test holes.

Even if it is assumed that the transmissive constants derived from the recovery curves are approximately correct, it is still virtually impossible to compute accurate rates of movement in the granite. In the velocity formula, V = PI all three variables are unknown or questionable in accuracy. The ef- p fective porosity (p) of joints and fractures is unknown, the gradient (I) is questionable due to somewhat ambiguous data, and the apparent permeability (P) must be determined by the transmissive constant (T) divided by the saturated thickness (m). The effective saturated thickness in the various tests is not known accurately because it is undoubtedly related to the fracture zones and joints that can only be roughly approximated from the lithologic and geophysical logs.

For these reasons it is concluded that it is not possible to compute accurately the rate of ground-water movement in the granite. On the basis of the data at hand the rate of movement must be extremely low, undoubtedly some fraction of that calculated for movement in the adjacent valley alluvium, and therefore the granite forms an effective barrier to rapid movement of contaminated water into the adjacent valleys.

SUPPLEMENT ON CHEMICAL DATA

Chemical Analyses

Throughout the hydrologic investigation for Project Shoal samples from most water points were periodically analyzed both for chemical and radiological content. The Las Vegas, Nevada office of the U.S. Public Health Service conducted the radiological analyses and retain the results of those analyses.

Appendix G tabulates the chemical analyses performed in the course of studics. Two laboratories conducted the chemical analyses: Abbot A. Hanks, Inc., San Francisco, California, and Hazelton Nuclear Science Corporation, Palo Alto, California. The two laboratory procedures differ only in method of expressing total dissolved solids, and that Hanks did not analyze for NO₃. The prevailing cations and anions of the analyses are expressed in equivalents per million and are totaled separately in Appendix G. In this manner the accuracy of the analysis can be roughly evaluated. If the sum of cations and anions is not within 20 percent of each other, it is probable that an error in analysis has occurred, or less likely, that constituents not considered in the analysis form a considerable percentage of the dissolved solids of the sample. Silica and total dissolved solids are expressed in parts per million.

It was noted that analyses vary considerably for several water points. Several explanations are possible, and perhaps the most obvious is the degree of accuracy in the analysis. Other possibilities are variations due to rates or frequency of pumping, periodic recharge with local stratification of the ground water, sample contamination, and perhaps even direct alteration by surface water due to well construction. It should be noted that variations occur both before and after the detonation, and no evidence firmly suggests shot-induced quality change. The paucity and quality of data does not permit the establishment of exact relationships on water quality variations. Illustration of relative concentration of some of the constituents from these analyses are shown in Figures 11 and 12. Concentrations of six ions, in equivalents per million, are shown by a method medified from that of Stiff (1951) and Sinclair (1962). The chief modification is that of scale. Where a linear scale was previously used, a logarithmic scale to make diagrammatically possible the illustration of a large range of concentrations is adopted.

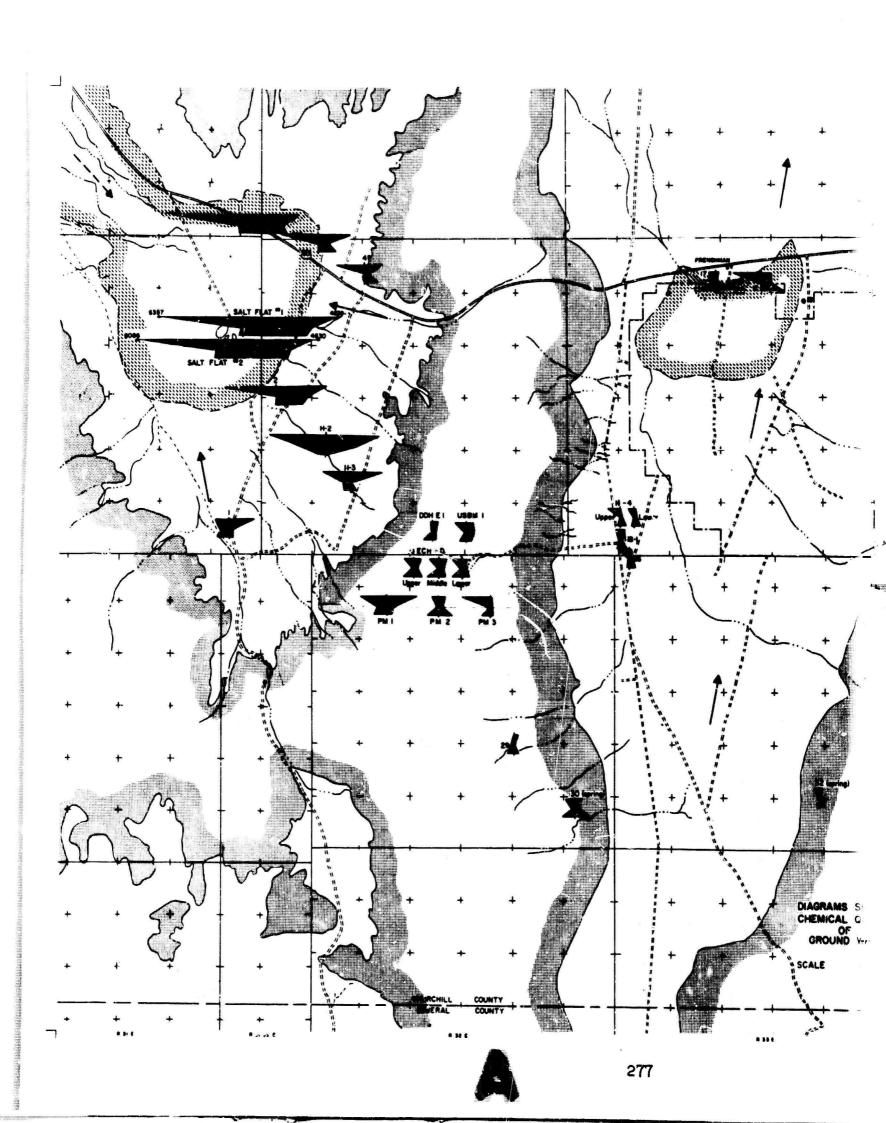
If the distribution of ion concentrations are compared with the regional directions of ground-water movement as indicated by the measured ground-water potential, a general pattern of water-quality change can be noted. In Figures 11 and 12 it can be seen that in general Na, C1, and SO₄, as well as total ion concentrations, markedly increase down gradient in the regional system. Local influences due to permeability, lithology, perched water, local evaporation discharge, and perhaps dilution of ion concentrations by local recharge are modifying factor3 in the general pattern.

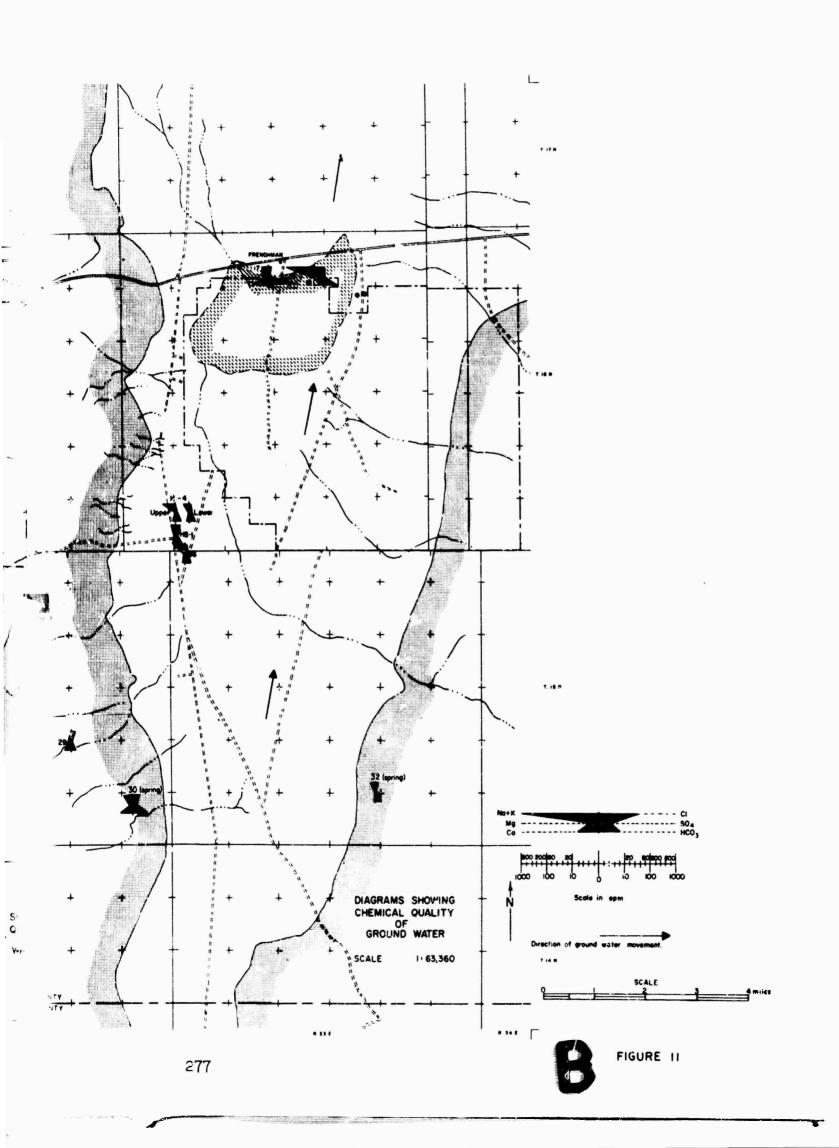
Ion concentrations and several other lines of evidence suggest that considerable recharge to the regional systems may occur in alluvial areas such as the alluvial slopes around Fourmile Flat adjacent to main washes, and in portions of Fairview Valley. This also may be true of the alluvium adjacent to Dixie Wash, where water-level fluctuations indicate recharge which would result in dilution and, therefore, in lower ion concentrations.

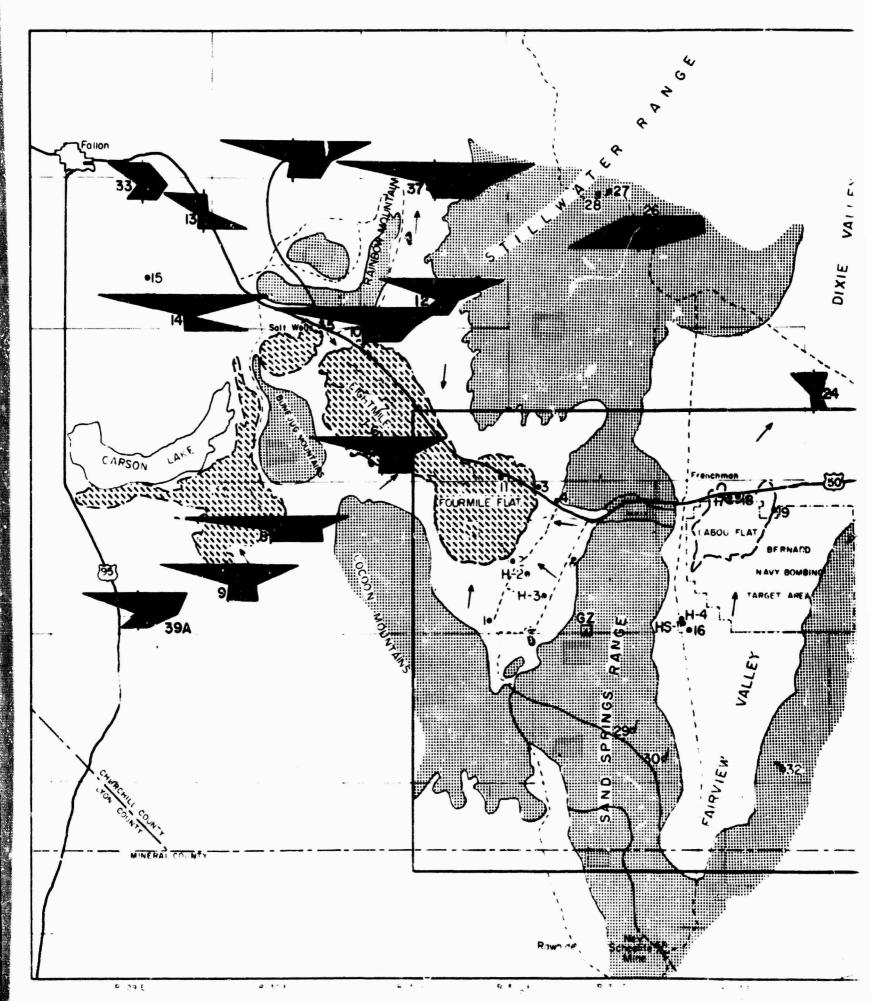
When analyses of water samples derived from the granite terrain are compared (see Appendix G) there is a range in total dissolved solids from 1,300 ppm at PM-1 to 210 ppm at W. P. 29. In samples from ECH-D that were taken from various depths it can be seen that the dissolved solids increase slightly with depth and presumably with age. Because drilling water was imported from HS-1, some of the analyses of the test-hole water samples from the vicinity of Ground-Zero may be of mixed waters comprised of water native to the granite and water from HS-1. Because of low dissolved solid concentrations in HS-1 water, the mixture would result in lower concentrations of solids.

The high content of dissolved solids in PM-1 may reflect several possible relationships, such as little loss of drilling fluid, very slow groundwater movement, or water which is much older than the other samples of the area. However none of these possible relationships can be substantiated with the data at hand.

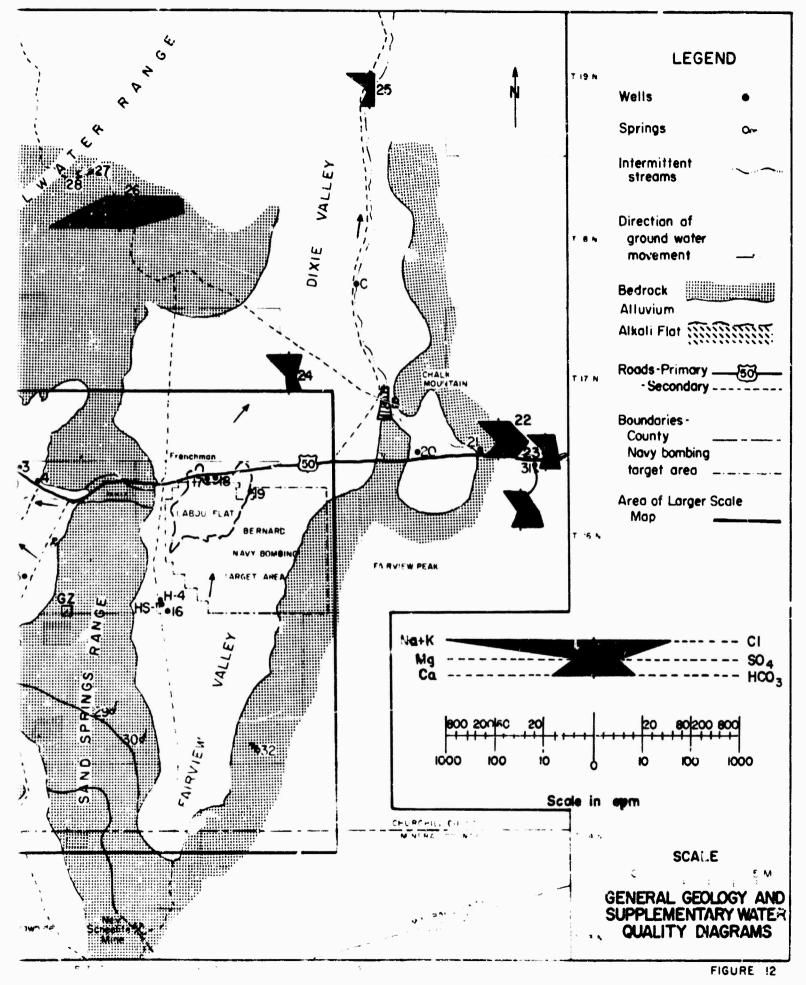
Perhaps the most significant chemical relationship of the bedrock waters can be seen when they are compared with waters from HS-1 and H-4 of Fairview Valley, and H-3 (in granite) of Fourmile Flat. It would appear that very little water of the test site area reaches the vicinity of HS-1 and H-4,











as here the concentration of dissolved solids is the same or lower than that in the granite. Furthermore, when the analyses of the water from H-3 and PM-1 are compared, the similarity is very close. Possibly because the transmissive media and sources are similar, the waters at these two points are in the same relative position in the flow systems on either side of the lidge of ground water that occurs under the Sand Springs Range. The potentials of the waters at the two points differ by over 300 feet. so perhaps the similar chemical compositions are more closely related to duration of time in contact with the granite and rate of movement or both.

Tritium Analysis

During the course of hydrologic studies in and adjacent to the Sand Springs Range several samples of ground water were analyzed for tritium content. This hydrogen isotope of mass 3 has a half life of 12.5 years and establishes a theoretical time scale of 0 to about 40 years when adequate controls are present. Before March, 1954, except for November, 1952, limited data indicates that the normal level of trit um in atmospheric and surface waters was in the neighborhood of 8 to 10 Tritium Units (T.U.) (8 to 10 tritium atoms to 10 hydrogen atoms). This tritium was generated by cosmic rays and extraterrestrial sources (Butt ar and Libby, 1955; von Buttlar, 1959; Giletti, Bazan, and Kulp, 1958). Since March, 1954, local analyses of precipitation have given values high as 2,160 T. U. (rrett and Huebner, 1960) and generally have remain a above 10 T. U. due to thermonuclear tests which release large concentrations of tritium to the atmosphere. Meteoric water which has reached ground-water systems since March. 1954, therefore, displays higher T. U. counts than the pre-1954 ground water, which if unmixed with older or younger water should now count 4 T. U. or less. For this reason in some situations tritium is a useful tool in ground-water studies, particularly in determining recharge, rate and direction of movement, and discharge. The results of analysis for tritium in the study area are shown in Table 2.

A number of variables must be considered when calculating the duration of time represented by tritium in the water samples of Table 2. Lacking are: adequate figures for tritium in meteoric waters in Nevada, the degree of mixing of old and young water in the samples, and the degree of stratification of various aged increments of recharge. It has been shown that stratification of ground water does occur under certain conditions (Carlston, Thatcher, and Rhodehamel, 1960) and it is probable that mixing of relatively young and old water also occurs, either under natural conditions or by supling processes. The analysis results at best tend to substantiate that recharge has occurred since 1954, in several environments of the area studied.

When test hole H-2 was drilled it was noted that the ground-water potential increased with increased depth of the hole without passing through recognizable confining lithologies. This relationship indicates a component of upward movement of ground water and is characteristic of a discharge zone. The potentiometric surface gradients in this area appear very low from measurements of four wells of different depths, and therefore the horizontal component of movement is likewise low. Discharge is by direct evaporation of capillary water, springs and seeps, one flowing well, and evapotranspiration from phreatophytes which rim the margin of

TRITIUM ANALYSES TABLE 2.

TRITIUM UNITS	7.0 ± 1.3	5.2 ± .5	43 ± 1.9	11.3 ± 1.0	Preliminary <45	
GENERAL REMARKS	Newly constructed cable tool wall, total pumpage prior to sample collection approx. 150,000 gals. 3.5' cone of depression initial static water level 112'. Perforations 120-765'. Pumped sample.	Bailed by hand, taken from top 20' of water in casing. Static water level 112', no pumping for approximately one year.	2-month old well, pumping at approximately 70 gpm since constructed. Initial static level 300', pumping cone of depression 35'. Perforations 415-510, 560-774. Pumped sample.	Sample from flowing drill hole in test site drift.	Bailed sample, uncased test hole, water level at 926' when sample taken.	
LABORATORY	Univ. of Calif.	Isotopes, Inc.	Univ. of Calif.	Isotopes, Inc.	Isotopes, Inc.	
DATE OF SAMPLE	6/62	6/63	6/62	7/63	8/63	
SAMPLE PT.	н-2	н-2	₹.	ECH E-1	USBM #1	

the Fourmile Flat playa. All of the discharge occurs approximately one-fourth of a mile and farther from test hole H-2, yet the low gradients and potential relationships indicate that the whole area, including H-2, hydrologically behaves as a discharge area. Even though this is a discharge area, precipitation on rare occasions undoubtedly infiltrates the 100 or so feet of unsaturated pervious alluvium to some degree. This water of direct recharge probably remains in stratified position at or near the top of the saturated zone for considerable time because of the upward decreasing potential of the old ground water and the lower density of the freshly infiltrated water with less dissolved solids. The casing of test hole H-2 is perforated from 135 feet intermittently to 750 feet, and therefore it is very likely that the pumped water sample collected in June, 1962 represents mixed waters. The bailed sample collected in July, 1963 is less likely to be as mixed, and could represent water from the 135-to 145-foot horizon.

The sample for HS-1 displays the highest concentration of tritium encountered in the samples analysed. It is known that the sample represents mixed water because of the method of sampling and the position and number of aquifers and the well construction. Also any water which recently infiltrated the alluvium would be involved in the cone of pumping depression and, therefore, probably in the pumper sample. Water from HS-1 was used for drilling water for the test and instrument holes of the test site. Therefore, it is expectable that the water lost during drilling operations was similar in tritium content.

The sample from Diamond Drill Hole E-1 of the drift is from an area underlain by a regional ground-water mound. Hydrologic data is suggestive of decreasing ground-water potential with depth, however the data is complicated by extracted and added water due to drilling and testing. This area is one in which recharge is necessary to maintain the ground-water mound, and therefore, occurrence of tritium is to be expected. However, the value is perhaps meaningless due to the possible communication with fracture systems where drilling water could be involved, and the possible natural or artificial mixing of different aged waters. If mixing and drilling water are not dominant factors, the value may be a reflection of recent recharge in the bedrock highlands. The orographic control on the rate and frequency of precipitation in Nevada allows for a relatively greater frequency of opportunity for recharge in the highlands. However, the highland lithologies are typically more impervious and therefore may reject a high percentage of available precipitation. Little data is available that indicates where the bulk of recharge occurs in arid terrains in Nevada. The tritium concentrations suggest the possibility of considerable recharge occurring in the alluvial fill. However, the data is too sparse and questionable to provide firm evidence.

The final tritium analysis is not available for the USBM #1 sample, however preliminary results indicate low values. The same unknown variables also apply to this sample with almost certain contamination by drilling water.

In summary, recharge in the alluvial terrain and perhaps in the bodrock terrain appears to have occurred since 1954 on the basis of tritium concentrations. This interpretation is reasonable in view of other lines of evidence gathered in the hydrologic studies.

REGIONAL FLOW SYSTEMS

Ground-water flow systems are based on a theory of ground-water motion whereby the system is in conformity with accepted principles of hydrodyramics. The concept requires that the direction of ground-water flow in space must be away from regions where mechanical (potential) energy per unit mass is higher and toward regions where it is lower. To satisfy a dynamic system water must be continually added to maintain the potential distribution and if it is not, the potential must decline. When the system is in equilibrium, the potential of the water at any given position remains constant, and the water entering the system equals the water leaving the system. Whether the systems that head in the Sand Springs Range are in equilibrium or not, under present conditions, precipitation is the only available source of recharge in the upland area near Ground-Zero. Some indirect evidence suggests that infiltration from precipitation does occur in the Sand Springs Range even though the average annual precipitation is low. The ground-water ridge or mound, the local ground-water discharge at W. P. 29 and 30, data which suggest decreased potential with depth, and perhaps the tritium content of the sample from ECH-E-1 all support this concept.

In recharge areas in which water moves downward from the air-water interface (the water table), it is observed that the deeper a hole is drilled the lower the water level stands in that hole, because the potential declines with depth due to a large component of downward movement of water. Conversely in a discharge zone the deeper the hole, the higher the water level because the potential increases with depth due to a dominant component of upward movement of water. This relationship suggests that in order to have so-called "artesian pressure" an aquifer need not be overlain by impermeable materials, but need only be located in a discharge zone where there is a component of upward movement of water, as is true in the vicinity of test well H-2.

Supporting evidence for a regional recharge area on the basis of ground-water potential was obtained in the test site area from water-level monitoring. Ferhaps the best example of decreased potential with depth is provided by the previously discussed elevations to which the water level recovered in ECH-D at different hole depths during similar time intervals. Also suggestive, but less reliable, are the initial water levels recorded in the closely adjacent but different depth holes PM-8 and ECH-D. The relationships between PM-8 and ECH-D are discussed under the subject Ground-Zero Water-Level Changes.

Supporting evidence for regional discharge zones on the basis of ground-water potential was gathered by monitoring water levels in test hole H-2, and to some extent from monitoring water levels in the shallow drill holes, W. P. 34, 35, and 36. Water levels in test hole H-2 gradually increased in elevation approximately 17 feet as the hole was deepened below the first indication of saturation. Significant in this situation was the total absence of observed confining horizons or aquitards. Water levels in the shallow holes also became higher as the holes were deepened although confining layers were penetrated. Additional evidence for a di 'harge zone comes from analysis of water levels in wells in Dixie Valley. In the vicinity of Dixie the deeper wells have higher static levels, a condition

which indicates discharge zones.

Several other lines of evidence support the existence of flow systems as delineated by the ground-water potentials. Chemical data collected in the course of the study generally indicates direction and rates of movement by ion concentrations. Areas of phreatophytes and surface salt accumulation delineate areas where evapotranspiration occurs. The tritium analyses also suggest areas where recharge may be occurring, but the evidence is weakened by lack of adequate control.

The ion concentrations noted in the various water samples denote several relationships: the areas of recharge indicated by low concentrations, the areas of discharge by high concentrations, and the areas of low rates of ground-water movement by rapid increase of ion concentration down gradient. The tritium and chemical analyses, and the marked fluctuations in water levels in some of the shallow wells in alluvium (see Appendix H) all lead to the conclusion that much of the water in the alluvium may be derived from recharge directly to the alluvium.

The two end points of the regional flow systems associated with the Sand Springs Range are also indicated by areas of evapotranspiration in Fourmile and Eightmile Flats and the vicinity of the Humboldt Salt Marsh in Dixie Valley. Topographically these two areas, with elevations of 3,900 to 3,800 feet, and 3,360 feet respectively, are the lowest parts of the region. Both areas are, in part, surface water features where standing water accumulates during periods of infrequent surface runoff within the respective topographic drainage basins. These two areas are the sinks for the two flow systems recognized on either side of the Sand Springs Range. In both flow systems natural discharge, indeed nearly all ground-and surface-water discharge, occurs at these sinks.

CONSEQUENCES OF SHOAL EVENT ON THE WATER SYSTEM

Preparations for Shoal Event Observations

Operational Procedures: The steps taken to implement the Hydrologic Safety Program and studies during detonation of the Shoal test are described below:

- 1) The three Laupold-Stevens water-stage recorders installed at test holes H-2, H-3, and H-4, were fitted with 24-hour time gears and 1:10 drum gears in order to exaggerate significant water-level fluctuations. These changes were made four days prior to the shot day so as to obtain pre-shot trends on a more sensitive scale. This gear combination was continued until four days after the shot whereupon the recorders were readjusted to produce the weekly records initiated at the start of the program.
- 2) Water levels in the test holes equipped with the Leupold-Stevens recorders were measured with steel tapes before and after the shot to validate the calibration of the water-stage recorders.
- 3) Water levels at all known water points within a 20-mile radius

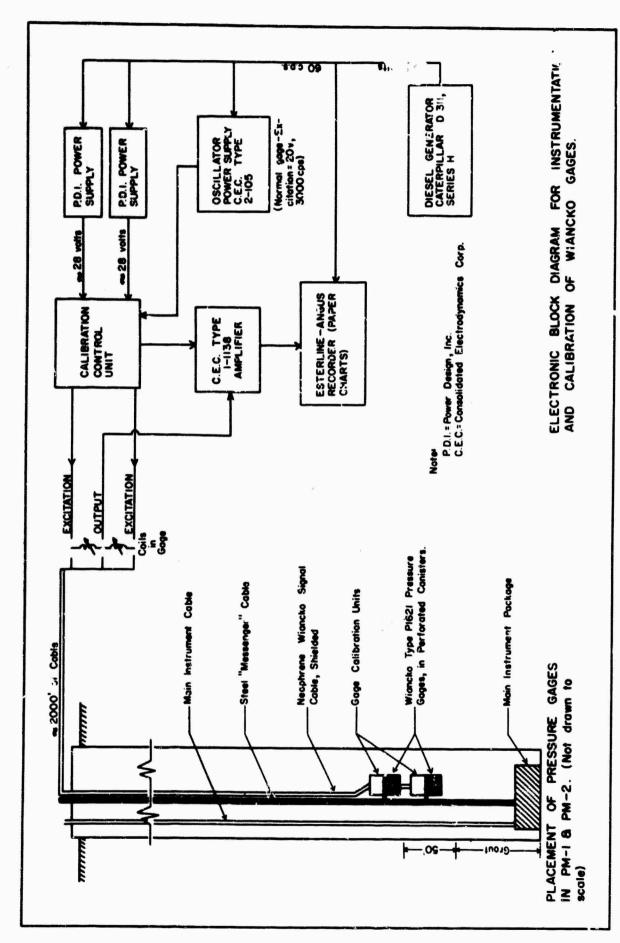
of Ground-Zero were measured before and after the shot. Measurements were initiated on October 23, 1963, and completed on October 29, 1963. In addition, one spring (W. P. 40) and seven wells in Dixie Valley (Table 1) were measured outside the 20-mile radius.

- 4) All water points adjacent to the Sand Springs Range were visited in the company of the owner or lessee concerned and a representative of the U. S. Public Health Service the day prior to the shot. At this time the points were measured and sampled. The local observers included: Mr. E. Weyher, Mr. E. Stark, Mr. M. E. Stark, Mr. E. J. Huckaby and Dr. C. P. McCuskey. Immediately, or as soon after the shot as possible, these same points were revisited and remeasured with the owner or lessee, excepting Mr. Stark, in attendance.
- 5) During the shot, certain water points, selected by reason of their proximity to Ground-Zero, were observed by personnel of the Desert Research Institute. These observations were made to obtain visual evidence of effects on water levels and rates of flow produced by the detonation and to reset or repair any instruments which might have been rendered inoperative by the shot-produced surface vibrations. These points were wells H-2, H-3, H-4 and W. P. 2 and 36. All points excepting H-4 which was downwind of possible venting, were observed at H-hour.
- 6) At D-day plus 30 days, during the period of November 26th and 27th, 1963, a sampling program was completed, obtaining water samples for both radiological and chemical analysis from all water points in the inventory schedule. The results of these analyses supplement the pre-shot sampling program. Subsequent periodic measurements and sampling continues to the publication date.

Water-Level Monitoring in PM-1 and PM-2

Two wells, PM-1 and PM-2, drilled near Ground-Zerc were instrumented with electronic pressure-sensitive devices in order to observe the response of water level to the Shoal Event. The depth of the two holes, and the additional instrumentation installed in the holes required the use of permanent gages for water-level measurements. In cooperation with Sandia Corp., Wiancko Type P1621 Pressure Gages were placed in the holes below the water level as shown in Figure 13. In order to determine the relationship between the electrical response of the variable inductors of the gages and the pressure due to water overlying the gages, a calibration system was also installed in the holes along with a calibration control on the surface. Figure 13 also depicts the generalized electrical system and requirements for operation of the gages.

The Wiancko gages of differing pressure ratings were installed in each hole. The gages are designed to withstand up to 150% of their individual rating; however, it is probable that the gages will continue to operate at higher pressures after experiencing a permanent strain resulting in a change in their pressure response and/or sensitivity. Hole PM-1 was fitted with a 0 to 100 psi gage and a 0 to 300 psi gage. Hole PM-2 was fitted with a 0 to 300 psi gage and a 0 to 500 psi gage. The gages are within one foot



TEST AS DEPLOYED IN EVENT. GAGES SHOAL WIANCKO PRESSURE-RESPONSE HOLES PM-I AND PM-2 FOR FIG 13

(vertically) of each other in each hole. The gages in PM-1 were covered by at least 60 feet of water or the equivalent of 26 psi. The gages in PM-2 were under up to 300 feet of water or the equivalent of 130 psi. Thus, the initial pressure conditions in each hole were well within the rated capacities of the gages.

The four gages were fed into a high-speed tape recorder about 1 minute prior to H-hour and recording at high speed was continued for about 2 minutes or until 1001 hours, 26 October 1963. The 100 psi gage in PM-1 and the 300 psi gage in PM-2 were also fed into the low-speed Esterline-Angus recorder during H-hour and recording continued for about 8 minutes after the shot. Both systems and all gages were calibrated electronically 50 seconds prior to H-hour and again a minute after H-hour. The calibration pulses were of 10-second and 20-second duration, respectively. The direction of the pulses as shown on the records is the same as an increase in water pressure. The calibration pulses are shown on Figure 14.

Responses

Wiancko Gages in PM-1 and PM-2: Figure 14 shows the low-speed recordings of the pressure variations in PM-1 (100 psi gage) and PM-2 (300 psi gage) immediately before, during, and after the shot. Since the two gages were monitored about twelve hours a day beginning in September, 1963, and no abrupt water-level fluctuations were observed, the abrupt rise in pressure at H-hour indicated on Figure 14 is a direct result of the detonation of the device. When the low sensitivity of the long-term recordings is considered, the relative thickness of the recorder trace makes minute measurements difficult.

The Wiancko gage in PM-1 experienced a press re increase equivalent to about 3 feet of water and this three-foot rise in water level apparently remained until the recorders were shut down, about eight minutes after the shot, and showed no indication of returning to the pre-shot base. The Wiancko gage in PM-2 experienced a pressure rise, as recorded in Figure 14, of the equivalent of about 67 feet of water. In the case of PM-2, however, the pressure curve began to return toward the pre-shot base immediately after the detonation and had sched a pressure equivalent to about 40 feet of water approximately 6 minutes after H-hour whereupon the trace began to flatten out. This is a drop of about 27 feet within a few minutes after H-hour.

The higher response of PM-2 to the pressure wave initiated by the detonation is probably correlative with the higher degree of fracturing found between Ground-Zero and PM-2 than was found between Ground-Zero and PM-1. If this higher degree of fracturing is present, the attendant slight increase in permeability would allow more direct transmission of pressure through the water system than would be possible in the less fractured system.

Figure 15 portrays the 1.6 inch per second playback of all four Wiancko Gages circumscribing H-hour. The traces on Figure 15 reflect the longitudinal pressure wave produced by the detonation. In the case of both PM-1 and PM-2, the gages indicate that a pressure fluctuation, below and above the pre-shot magnitude of pressure, reaching a maximum of 200 psi, was produced in the test holes after the shot. This pressure is equivalent to the pressure produced by a 460-foot column of water. Fluctuations in the water

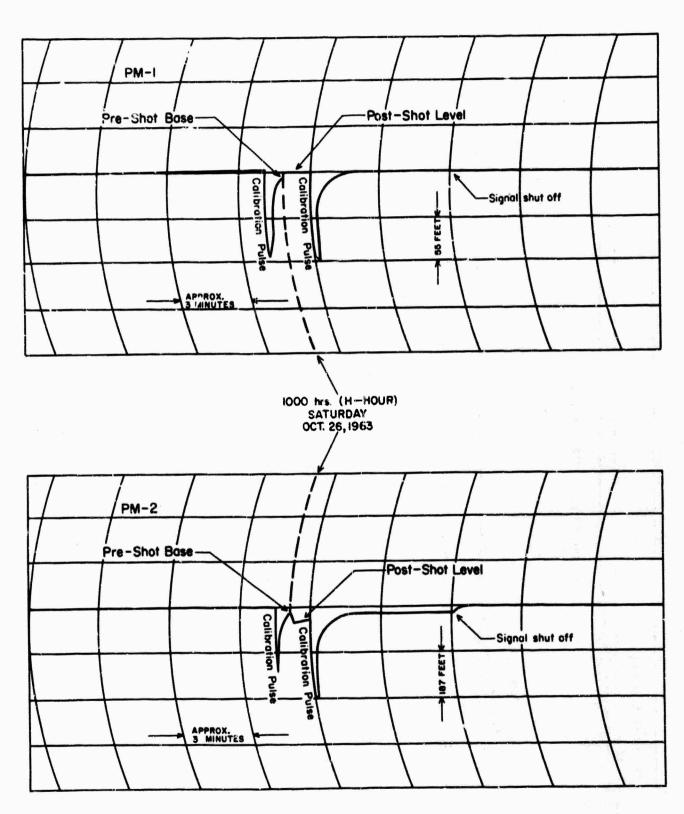
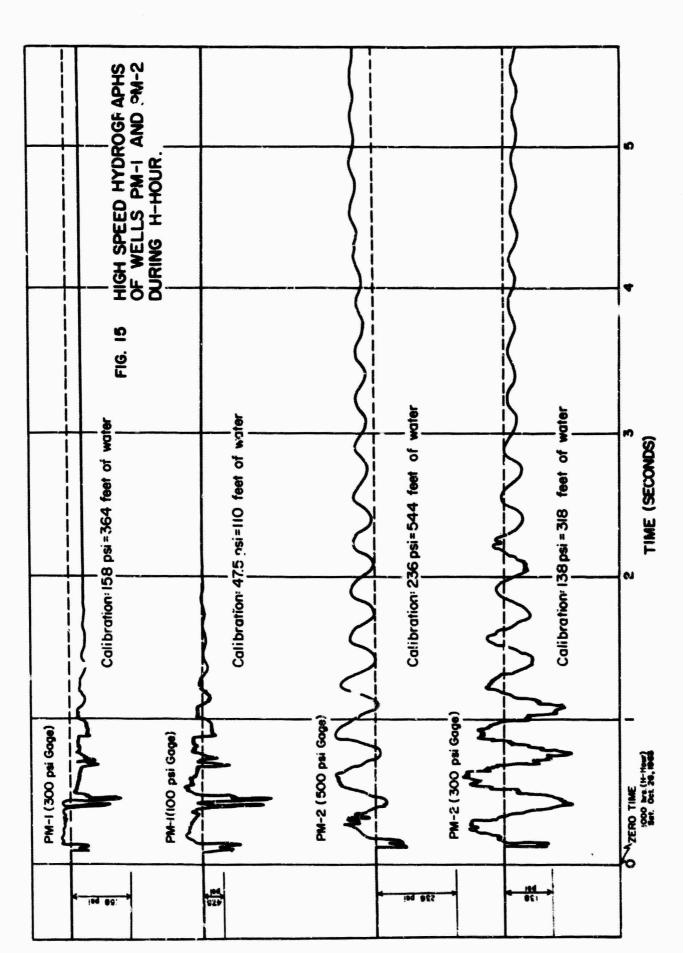


FIG. 14 PRE AND POST SHOT HYDROGRAPH OF WELLS PM-I AND PM-2 AS RECORDED BY WIANCKO PRESSURE GAGES



level of this magnitude, within the time (less than 0.05 second) involved, are impossible and therefore the pressures cannot be directly correlated with changes in water levels.

However, after the cyclic fluctuations have ceased, a measurable change in water level is indicated by each Wiancko gage. This digression from the pre-shot levels remains for the one-minute period during which the high-speed recorder was run after H-hour and shows no indication of immediately returning to pre-shot levels. Therefore, the digressions are considered to be indicative of the actual changes in water levels in PM-1 and PM-2, barring electronic shifts in response as will be discussed for one gage trace.

The 100 psi gage in PM-1 indicated a 5-foot rise in water level, observable in the trace about 4 seconds after H-hour. This agrees closely with the 3-foot rise recorded by the same gage on the low-speed recorder. The 300 psi gage in PM-1 indicated on the order of a 50-foot rise in water level, observable in the trace about 2 seconds after H-hour. Though the sensitivity of the 300 psi gage may be expected to be less than that of the 100 psi gage, the divergence in readings is not easily explained. However, as may be seen below, the 50-foot rise is still less than the rises shown in PM-2.

The 300 psi gage in PM-2 indicated a 60-foot rise in water table, observable in the trace about 10 seconds after H-hour which closely corresponds with the 67 feet indicated by the same gage on the low-speed recorder. The 500 psi gage in PM-2 parallels the cyclic fluctuations shown by the 300 psi gage in the same hole, but after 10 seconds, indicates a 190-foot lowering of water level. Since the general result of the pressure wave seems to be a rise in water levels, the response of the 500 psi gage is probably due to an electronic readjustment in the recording system. Such a readjustment or strain is also suggested by the fact that the spurious inflections recorded by the 500 psi gage are reproduced as the reverse of the same fluctuations in the 300 psi gage in PM-2. It therefore seems reasonable to ignore the trace of the 500 psi gage in considering quantitative changes in water level.

The high-speed records of Figure 15 thus correlate with those of the low speed previously mentioned, showing a higher rise in water level, about 65 feet, in PM-2 than the rise shown in PM-1, between 5 and 50 feet, but more likely about 5 feet.

Figure 15 also shows that the effect of the Wiancko gage rated at the relatively lower pressure was to emphasize the fluctuations shown by the higher-rated gage. The minor fluctuations occurring along the broad sine-type curve are probably due to anomalies in the pressure field caused by interference of the cables and gages in the holes during duration of the intense pressure waves. The pressure oscillations in PM-1 begin to assume a sine-wave pattern 0.8 of a second after H-hour. The wave has a frequency of approximately 5 cycles per second. The pressure wave in PM-2 assumes a sine-wave pattern about 0.12 of a second after H-hour and has a frequency of approximately 3.1 cycles per second.

The initial disturbance of the traces in Figure 15 occurred 0.12 of a second after Zero time in the case of both test wells. PM-1 is 1,960 feet southwest of Ground-Zero and well PM-2 is 1,959 feet north-northeast of Ground-Zero. The initial energy pulse reaching the pressure gages therefore

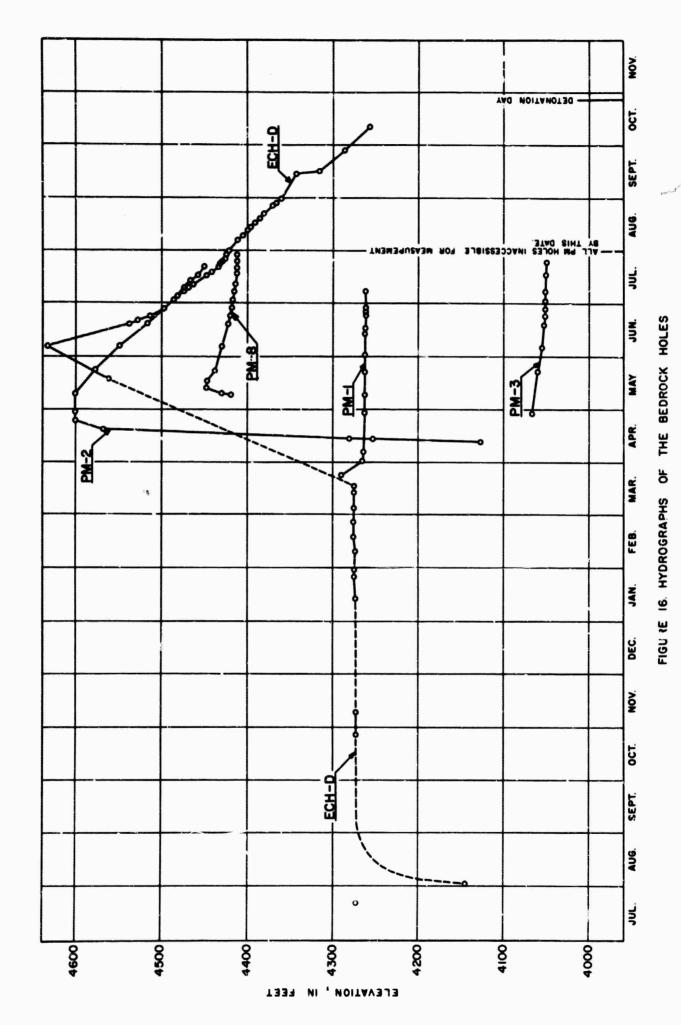
travelled at a speed of approximately 5 Km/sec. which agrees closely with an assumed velocity of 5.5 Km/sec. for a granite with a density of 2.7 g/cm³. Certain fracture systems could reduce this theoretical velocity.

Ground-Zero Water-Level Changes: The interpretation of water-level measurements in the vicinity of Ground-Zero is complex ambiguous data results from numerous unknowns. General relationships are based on water-level measurements in ECH-D, PM-1, PM-2, PM-3, PM-8, and USBM #1.

Hydrographs of these measurements appear in Appendix H. Factors which lend ambiguity to the water-level readings are introduced drilling and testing waters; water removed during shaft and drift construction, as well as water removed during various tests; unknown variability in fracture density, permeability, storage, and communication; and sparse measurements from holes of various depths.

The validity of data on the potentiometric surface in the vicinity of Ground-Zero is questionable due to the effect of drilling and testing activities. Considerable amounts of water were involved in construction of exploration and instrument holes. In the low-permeability granite this introduced water should be assumed to be an influencing factor on water level. Evidence of this is apparent in the area including the ECH-D, PM-8, USBM 41, and ECH-A holes. Water levels in these holes over a period of time ranged between 4,625 and 4,266 feet in elevation. Despite this degree of anomaly in water levels near Ground-Zero, the general gradients for the Sand Springs Range in the working area of the project can be described as sloping toward Fairview Valley. A ground-water divide is postulated as lying northwest of the shaft; therefore, the main component of lateral movement of the ground water in the vicinity of the shot point is southeast toward Fairview Valley.

Initial water levels recorded after the boll tests in the bedrock holes adjacent to Ground-Zero indicate a potentiometric gradient of approximately 800 feet per mile to the southeast, if measured from PM-2 to PM-3. However, from PM-3 toward the vicinity of H-4 in Fairview Valley the gradient in the granite can be no more than approximately 70 feet per mile. In comparison, within the alluvium of Fairview Valley the potentiometric gradient is approximately 3 feet per mile in a northerly direction. It is expectable that the gradients in the low permeability medium of granite should be much higher than those in the much more permeable alluvium, however the marked difference between 70 feet per mile and 800 feet per mile raises the question as to how much of this apparent gradient in the test site area might be the result of introduced water. It should be pointed out that at every point of control in the test site area the water levels may be greatly influenced by introduced water because of the probable very low storage capacity of the fractured granite. In Figure 16 the hydrographs of the bedrock holes where measurements were possible are plotted for comparison. ECH-A and USBM #1 hydrographs are omitted due to lack of sufficient data to establish trends. The 350-foot plus rise of ECH-D during the spring of 1963 while the PM holes were under construction suggests that much of the ground-water mound and associated gradients may be the result of introduced drilling water.



If the initial levels of recovery in the PM holes are assumed to be indicative of pre-construction conditions of saturation, the close proximity and the 1,200-foot difference in depth of PM-8 and ECH-D permit the comparison of the change in ground-water potential with depth. Initial water-levels, after the recovery tests in PM-8, were approximately 175 feet higher in elevation than initial water-levels after the recovery tests in ECH-D (which is approximately 1,200 feet greater in depth). However, this relationship may be unreliable because during the time interval when simultaneous measurements could be made in both holes, the ECH-D level was always higher than the level in PM-8 as the result of the previously-mentioned 350-foot plus rise in ECH-D. The maximum difference in water-level elevations during the simultaneous measurements was over 200 feet, but, because of a relatively rapid decline in ECH-D water levels after the 350-foot rise, the last PM-8 measurement made in July, 1963 was very close to the ECH-D level at that time. Figure 16 illustrates these relationships.

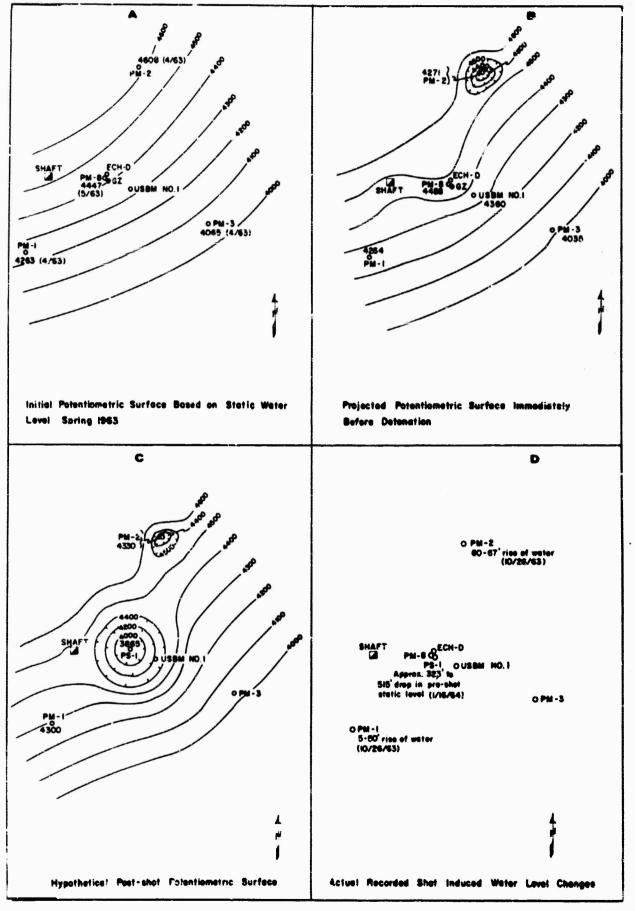
The water-level declines at varying rates in the bedrock holes are interpreted to be the result of some combination of the following factors:

- 1) The decline caused by dissipating cones of impression which were formed during the rotary drilling hole construction.
- 2) The decline of the saturated zone produced by differential potential within the granite adjacent to uncased wells. Water with a high potential may flow into the open holes, then flow downward through the hole with very little potential loss, and then re-enter the granite when water at a lower potential occurs. This phenomena is somewhat analogous to an electrical circuit. This "short-circuit" effect would produce a core of depression adjacent to the hole.
- 3) The decline in the saturated zone adjacent to the hole because of dewatering associated with the drift construction. The proximity of PM-8 and ECH-D to the drift perhaps makes these holes most susceptible to this possibility. However, as illustrated by Figure 16, PM-2 and ECH-D hydrographs display the largest and most rapid declines which might be associated with drift dewatering.

Furthermore, the actual rates of decline, regardless of the causal factors, may also be influenced by the number, position and extent of encountered fractures in the granite, and the degree of clogging of these fractures produced by the drilling process.

Parts A, B, and C of Figure 17 display diagrammatic potentiometric surfaces determined on the basis of available measurements. In all probability the diagrams are inaccurate as to actual conditions, but the previously-mentioned problems negate attempts to illustrate precise conditions. The potentiometric surfaces are primarily based on the following criteria and assumptions:

1) The first static levels obtained after bail tests in the spring of 1963 are assumed to be indicative of the configuration of the undisturbed regional saturated zone (an unjustified assumption due to addition of construction and testing water, and differences in



GROUND ZERO AREA

Figure 17

measurements of potential obtained from holes of differing depths.

2) Subsequent water-level fluctuations are assumed to be the result of either cones of depression forming around test holes due to "short circuit effect" draining because of decreased potential at depth, or cones of impression forming because of introduced drilling and test water from adjacent holes. Figure 18 illustrates idealized diagrams of interpreted conditions over various periods of time. The configuration of the induced zones of saturation in Figure 18 are schematic and perhaps unrealistic due to the random nature of the fracture zones where most and perhaps all changes in saturation occur on a short-term basis.

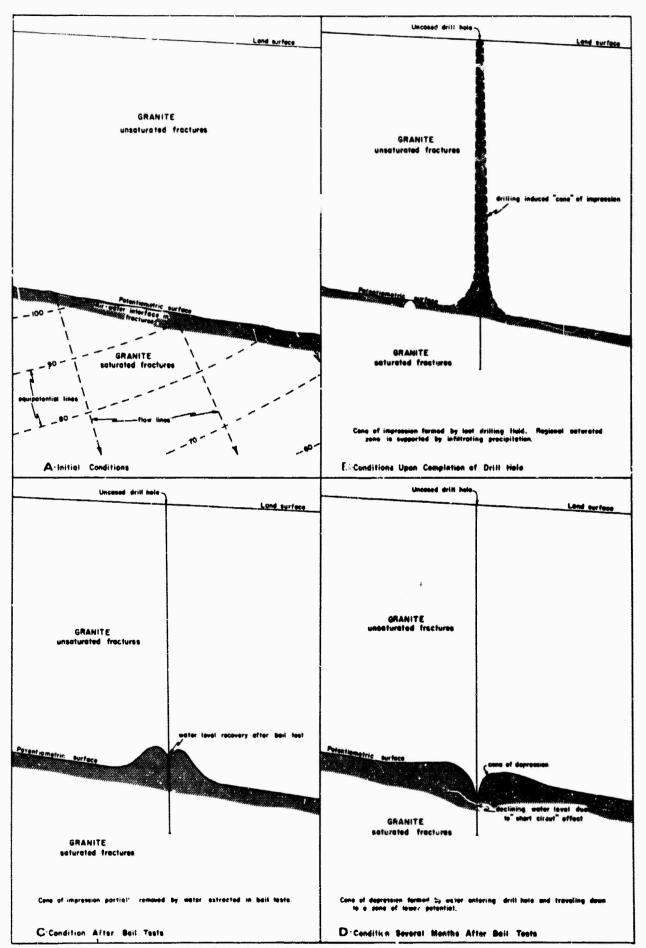
The approximate net effect of the two factors can be seen by comparing A and B in Figure 17, where the potentiometric surface in B is based upon projected water levels. These water levels were determined by projecting the rate of decline in the monitored holes during the last month of measurements prior to the instrumentation of the holes.

Water levels in PM-8 are utilized in the Ground-Zero vicinity as the great depth of ECH-D and the resulting lower potential does not reflect the true position of the saturated material. PM-2 and PM-3 are assumed to have developed drain comes due to the "short circuit effect" of decreased potential at depth in uncased holes. This assumption, at least in part, is in error, but was made arbitrarily to simplify the construction of the potentiometric surface. It is probable that the declines in water level in the holes are in response to two other factors combined with the "short circuit effect". The slowly declining water levels may in part be the result of the cones of impression of drilling fluid gradually spreading and declining, and perhaps, in part, the result of drift dewatering in those holes closely adjacent to the drift. It is not known which is the dominant factor, but the hydrograph of ECH-D strongly suggests that the large rise and subsequent decline to below the initial static level is largely in response to introduced drilling fluid from the nearby test and instrument holes construction. However, decline to below the initial static level indicates that more than just a cone of impression of introduced drilling fluid is involved.

Knowledge of shot-induced changes (Figure 17, C and D) is limited to questionable pressure gage recordings in PM-1 and PM-2, and data obtained in PS-1 (Post-Shot Hole 1) which shows a sharp temperature drop logged during January 16, 1964, (Korver, Boardman, Rawson: UOPKA 64-7; Feb. 4, 1964). The actual changes noted are shown in D of Figure 17.

In summary, it appears that both during the construction phase and during the shot, the natural configuration of the saturated zone was considerably modified locally, but the extent of modification was not enough to materially alter the regional flow system, and no new points of discharge are likely to develop from the changes.

Leupold-Stevens Type F. Recorders on H-2, H-3, and H-4: Figure 19 shows the Leupold-Stevens recorder charts for the shot period as recorded for wells H-2, H-3, and H-4. The top graph shows the barometric pressure fluctuations for the same period. Prior to the detonation, the water-level fluctuations of H-2, H-3, and H-4 may be attributed to barometric pressure fluctuations or



DIAGRAMMATIC HYDROLOGIC HISTORY OF BEDROCK TEST HOLES GROUND ZERO AREA

FIGURE IS

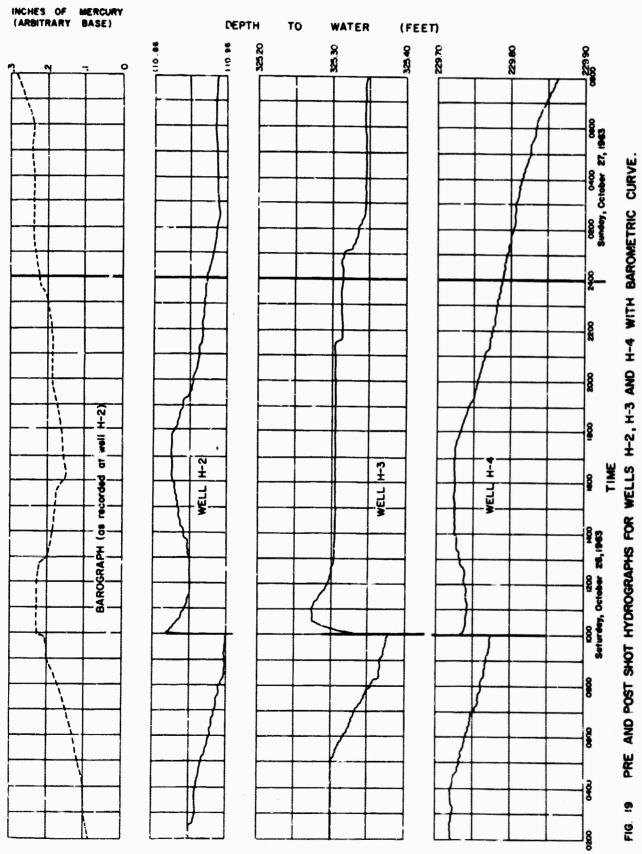


FIG. 19

nearby pumping in the case of H-4. The abrupt water-level fluctuations as shown by Figure 19 are the effects of the detonation.

After a short-lived oscillation at H-hour derived from the surface shock of the detonation and differential movement between the recorder and the water surface, the water-level trace of well H-2 showed an immediate rise of 0.08 feet from the pre-shot level of 110.96 feet below ground surface up to 110.88 feet. The water level then began a 24-hour return to near the pre-shot level.

As was the case for H-2, the water levels in well H-3 also experienced a short-lived oscillation. Immediately after the initial shock, the water level in H-3 continued a rapid rise from the pre-shot level of 325.38 feet below ground surface to a point about 325.34 feet whereupon the level continued to rise but did so at a slower rate, taking an additional 30 minutes to reach a maximum of 325.28 feet. This was total increase in water level of 0.10 foot. The water level then began a 24-hour return to the pre-shot level, reading 325.39 feet below ground surface at 1000 hours the following day.

Figure 19 also shows that the recorder on well H-4 experienced the initial oscillations due to ground shock. The subsequent curve differs slightly from those of wells H-2 and H-3 in that the trace begins a downward path after it has risen to its peak at H-hour; however, the difference is probably due, in part, to a difference in barometric pressure change at well H-4 as opposed to well H-2 where the barometer was recording and, in part, to difference in barometric efficiency. The effect of the detonation was an immediate rise in water level at H-4 from 229.77 feet below ground surface to 229.74 feet at H-hour. This rise of 0.03 feet in water level was then followed by a gradual return of the water level toward the pre-shot base, reading 229.77 feet below ground surface about 15 hours after the shot. Therefore, the water level in well H-4 required slightly less time to return to its pre-shot level than did the levels of wells H-2 and H-3.

Well H-3, which experienced a relative delay in obtaining its maximum rise (Figure 19), penetrates the granite aquifer while wells H-2 and H-4 penetrate alluvium aquifers. The lower storativity and nearer hydrologic connection with the point of detonation may account for the relatively higher rise in water level in H-3 as compared to the rise in H-2 and H-4. The rise in H-3 is 0.02 of a foot higher than that measured in H-2. The primary difference between the hydrographs of the three "H" holes is the time delay the water level in H-3 experienced while rising to its highest level. This retarded response may be a result of the aquifer characteristics of the granite.

Other Measured Water Points: One other water point, W. P. 1, showed an apparent change in water level occurring during the period from 0800 hours October 25, 1963, to 0800 hours October 27, 1963. This well, used by Dr. C. P. McCuskey and located to the west of the Sand Springs Range, measured 285.28 feet to water level on October 25, 1963 and when again measured on C tober 27, 1963 the water level was 283.88 feet below ground surface. This rise in water level of 1.4 feet was checked with repeated measurements by steel tape. The level of 285.28 is in close agreement with the previous

pre-shot neasurements made since February of 1962. Then on October 29, 1963, the well was again measured and the depth to water found to be 285.50 feet. An additional measurement on the 26th of November, 1963, showed the water level to be 285.25 feet below ground surface. This last reading was made at least 24 hours after the well had been pumped while the other readings were made when no pumping had occurred for at least six months. The post-shot reading at W. P. 1 of 283.88 feet is the single anomalous depth in the measurement series. It is believed that the 1.4-foot rise is not cor. relative with the hydrologic system as affected by the shot but perhaps may be due to a mechanical disturbance of the well resulting in the dropping of detrital material down the hole. This well is somewhat difficult to measure in that the only entrance for measuring is a small hole in the casing below ground level. Several times after the noted rise occurred, this well became clogged with detrital material, presumably due to casing failure and caving. The condition of the casing at depth is unknown, but it is presumably weak due to age and the corrosive action of the ground water.

Comparison of Detonation and Earthquake Tluctuations: Earth displacements known to have occurred in seismically-active areas have caused considerable hydrologic changes. For example, many authors report changes in discharge of springs and flowing wells as well as fluctuations of water levels in wells. One of these reports (Zones, 1957) deals with Dixie and Fairview Valleys. In this area, water-level fluctuations on the order of four to eleven feet and discharge changes occurred in the epicentral area of the 1954 earthquakes. Two earthquakes of 7.1 and 6.8 magnitude (Richter) occurred on 16 December 1954 with epicenters and surficial displacements in the Fairview Peak and Dixie Valley area. Zones (1957, pp. 395-396) reports that water-level and discharge changes resulted primarily from tilting of aquifers, compaction of sediments over large areas, fracturing of rocks, and movement along faults. The water-level changes are transitory in nature and apparently there is subsequent readjustment to pre-disturbance conditions of discharge.

The magnitude and extent of water-level fluctuations induced by the detonation at the test site are as might be expected when compared with those induced by the 1954 earthquakes. The total energy released in a 12-kiloton detonation and that energy-associated magnitudes of approximately 7 on the Richter scale are so diverse that hydrologic modifications may not even be comparable. Furthermore, the actual earth displacements which cause most of the water-level changes reported by Zones are almost nonexistent in the case of the detonation, thus all water-level changes on a regional basis are short-lived fluctuations due to seismic waves.

Summary of the Consequences: Within the readable and recording accuracy of the instrumentation employed, Table 3 summars is the results of the SHOAL Event on the test wells observed. Water levels in all of the instrumented wells experienced a rise ranging from in excess of 65 feet in PM-2 to a rise of less than 0.04 feet in H-4. The water in the "H" wells returned to its pre-shot level, usually within 24 hours or less. The water in the PM holes, as indicated by the partial record obtained for PM-2, are either in the process of gradually returning to or close to its pre-shot levels. Preliminary data concerning the AARDVARK Event as reported by Garber (1963) suggests that water levels disturbed in this manner tend to recover toward their pre-shot base. The rapidity and extent of recovery to previous conditions of

TABLE 3. EFFECT OF SHOAL EVENT ON WATER SYSTEM AS INDICATED BY INSTRUMENTED TEST WELLS

	Pressure gage indicates 3-foot rise in water level occurring at H- hour and continuing.	Pressure gage indicates a rise of less than 5 feet (Difficult to observe on chart) and continuing.	Pressure gage indicates a rise of 50 feet, occurring at H-hour and continuing.	Pressure gage indicates 67-foot rise in water occurring at H-hour and decreasing.	Pressure gage indicates 60-foot rise in water occurring for record period.
TYPE OF	Wiancko gage rated at 100 psi recording on low-speed E. A. paper chart recorder (5 inches per minute).	Wiancko gage rateviat 100 psi recording on high-speed tape re- corder. Paper printed at 1.6 and 16 inches per second.	Wiancko gage rated at 300 psi recording on high-speed tape recorder. Paper printed at 1.6 and 16 inches per second.	Wiancko gage rated at 300 psi recording on low-speed E. A. paper chart recorder (4.5 inches per minute).	Wiancko gage rated at 300 psi recording on high-speed tape recorder. Paper printed at 1.6 and 16 inches per second.
GEOLOGIC	Granite	Grani te	Granite	Granite (Fractured)	Granite (Fractured)
CASING PER-	Not cased	Not cased	Not cased	Not cased	Not cased
DEPTH OF DEPTH TO CASING PER HOLE (FT.) WATER (FT.) FORATIONS	1095	1095	1095	1048	1048
DEPTH OF HOLE (FT.)	1350	1350	1350	1305	1305
WELL NO.	PM-1	PM-1	PM-1	PM-2	PM- 2

TABLE 3. CONT. EFFECT OF SHOAL EVENT ON WATER SYSTEM AS INDICATED BY INSTRUMENTED TEST WELLS

SHOAL EVENT EPFECT	Pressure gage indicates 190-foot lowering of water occurring after H-hour and continving for period of record.	Greater than 515 feet downward displacement of the potentiometric surface approximately 3 months after shot.	After surface vibrations, recorder indicates a rise in water level of 0.08 feet at H-hour and decreasing.	After surface vibrations, recorder indicates a 30-minute rise in water level of at least 0.104 feet occurring after H-hour and decreasing.	After surface vibrations, recorder indicates a rise in water level of 0.036 feet occurring at H-hour and decreasing.
TYPE OF INSTRUMENT EMPLOYED	Wiancko gage rated at 500 psi recording on high-speed tape ra-corder. Paper printed at 1.6 and 16 inches per second.	Temperature log of the re-entry hole showing abrupt drop at 1365-foot depth, and continue constant temperature below.	Leupold-Stevens 24-hour recorder magnifying water-level fluctuations by 10.	Same as H-2	Same as H-2
GEOLOGIC AQUIFER	Granite (Fractured)	Granite (Shattered and frac- tured)	Alluvíum	Granite	Alluvíum
CASING PER- FORATIONS	Not cased	Perforated drill stem	135-245 270-372 640-	260-455 plug = 455	420-520 612-710* 720-860 867- *708 = plug
DEPTH TO WATER (FT.)	1048	1365	111	325	299
DEPTH OF HOLE (FT.)	1305	1389kb	768	480	935
WELL NO.	PM-2	PS-1	н-2	н-3	7- н
		300			

saturation is not known, but the estimate of water level in the post-shot No. 1 test hole at 1,365 feet of depth approximately three months after the shot indicates the rates are relatively slow (the original depression of ground water by the shot near the detonation point is also unknown). The recovery in the immediate shot zone is undoubtedly related to several factors such as shot-induced fracturing, which probably has greatly increased the permeability and void volume in the affected zone, and the high temperatures which would inhibit liquid phase water invasion. Return of the water might also be inhibited by compression and melting with subsequent hardening of the rock. An obstruction in PS-1 at approximately 1,240 feet has prevented any measurements of the water level subsequent to January 12, 1964.

Lasting effects upon the ground-water system beyond the Ground-Zero vicincity are apparently nonexistent, as predicted from preliminary studies. Rates of movement and the configuration of the saturated zone have not been measurably altered by the detonation beyond the granite test holes adjacent to Ground-Zero. Water quality is also unimpaired at presently existing points of discharge. Other studies (Higgins, 1959) indicate that when the ground water that was proximate to the detonation finally reaches points of discharge, the radioactive contamination will long since have been reduced to undetectable levels by fixation of the radionuclides.

CONCLUSIONS

Findings subsequent to those available in the preparation of Part I of this report do not alter the initial conclusions that the detonation will have little or no detrimental effects on the associated ground-water systems. The subsequent data tends to substantiate the initial conclusions. The following relationships have been found:

- 1) The detonation site is in a zone of ground-water recharge. This relationship is suggested by the apparent decrease in potential with depth, the ground-water ridge or mound, and some precipitation infiltration.
- 2) The rate of ground-water movement in the vicinity of the detonation site is low. This is shown by recovery tests, steep potentiometric gradients, and rapid increases in ion concentration down gradient.
- 3) The direction of movement of the contaminated water is southeastward toward Fairview Valley with a large component of downward movement. This is indicated by decreased potential with depth, potentiometric gradients sloping toward the valley, and the increase in ion concentrations with depth and distance down gradient.
- 4) It is highly unlikely that water contaminated with radionuclides will reach areas of ground-water utilization or discharge. The rate and direction of movement will permit fixation of the radionuclides before the water reaches these areas.

The data indicates that possibly all water adjacent to the detonation is moving toward Fairview Valley, and thus the minimum amount of granitic terrain it must pass through before reaching the alluvial aquifers of the valley is approximately two miles.

If the conclusion is in error that the rate of movement of water in the granite is only a fraction of that in the alluvium and, in fact, the rate approaches that computed for the valley fill, the water would travel approximately 30 feet per year, and therefore a time lapse of approximately 350 years would occur before any water associated with the detonation would reach the alluvium. Once it reached the alluvium, another 260 years would be required for the water to reach the vicinity of HS-1 at the present gradient. It can be seen that the distances involved permit wide margins of error in ground-water movement rates before time factors become critical.

REFERENCES CITED

- Antevs, Ernst, 1945, Correlation of Wisconsin glacial maxima: Am. Jour. Sci., v. 243-A, Daly volume, pp. 1-39.
- Basin, with emphasis on glacial and postglacial times: Utah Univ. Bull., v. 38, no. 20 (Biol. Ser., v. 10, no. 7), pp. 168-191.
- Rundschau, v. 40, no. 1, pp. 94-108.
- Barrett, E. W., and Huebner, Leonid, 1960, Atmospheric tritium analysis: Chicago Univ., Tech. Progress Rept. no. 2, Contract AT (11-1)-636, Feb. 16.
- Carlston, C. W., Thatcher, L. L., and Rhodehamel, E. C., 1960, Tritium as a hydrologic tool The Wharton Tract Study: Int. Assoc. Sci. Hydrology, no. 52, pp. 503-512.
- Garber, Murray S., 1963, Large rise and following decline of water level in Well 7 Area 3 Nevada Test Site An effect from the AARDVARK undernuclear explosion: U. S. Department of the Interior, Geol. Survey, Technical Ltr. Yucca-48.
- Giletti, B. J., Bazan, F., and Kulp, J. L., 1958, The geochemistry of tritium: Am. Geophys. Union Trans., v. 39, pp. 807-818.
- Higgins, G. H., 1959, Evaluation of the ground-water contamination hazard from underground nuclear explosions: University of California, Ernest O. Lawrence Radiation Laboratory No. UCRL-5538 Revised, 23 pp.
- Jones, J. C., 1914, The geologic history of Lake Lahontan: Science, v. 40, pp. 827-830.
- ______, 1925, The geologic history of Lake Lahontan, in Quarternary Climates: Carnegie Inst., Washington Publ. 352, pp. 1050.
- no. 3, pp. 533-540. Geol. Soc. Amer. Bull., v. 45,
- Morrison, R. B., 1961a, Lake Lahontan stratigraphy and history in the southern Carson Desert (Fallon) area, Nevada, in Short papers in the geologic and hydrologic sciences: U. S. Geol. Survey Prof. Paper 424-D, pp. D111-D114.
- Bonneville and the glacial sequences of the Sierra Nevada and Wasatch Mountains, California, Nevada, and Utah: U. S. Geol. Survey Prof. Paper 424-D, pp. D-122-D-124.
- , 1964, Lake Lahontan: geology of southern Carson Desert, Nevada: U. S. Geol. Survey Prof. Paper 401, 156 pp.

- Russell, I. C., 1885, Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11.
- Sinclair, W. C., 1962, Ground-water resources of Desert Valley, Humboldt and Pershing Counties, Nevada: State of Nevada, Department of Conservation and Natural Resources, Ground-Water Resources Reconnaissance Series, Rept. 7, 23 pp.
- Stiff, H. S., 1951, The interpretation of chemical water analyses by means of patterns: Jour. Petroleum Technology, Oct., pp. 15-17.
- Tocher, D., 1956, Movement on the Rainbow Mountain Fault: Seismol. Soc. America Bull., v. 46, pp. 10-14.
- Zones, C. P., 1957, Changes in hydrologic conditions in the Dixie Valley and Fairview Valley areas, Nevada, after the earthquake of December 16, 1954: Seismol. Soc. America Bull., v. 47, no. 4, pp. 387-396.
- von Buttlar, H., 1959, Ground-water studies in New Mexico using tritium as a tracer: Jour. Geophys. Res., v. 64, pp. 1031-1038.
- von Buttlar, H., and Libby, W. F., 1955, Natural distribution of cosmic-ray produced tritium: Jour. Inorganic and Nuclear Chemistry, v. 1, pp. 75-91.
- von Buttlar, H., and Wendt, Immo, 1958, Ground-water studies in New Mexico using tritium as a tracer: Trans., Amer. Geophysical Union, v. 39, no. 4, pp. 660-668.

A PENDEK G.

CHRICCAL ARALYSIS OF MATER POINTS, TEST BULE, AND SURFACE MATES SAMPLES PROJECT SHOAL, CHRICKILL COUNTS, MEYADA Quantities is Equivalents for Milles

CORF *Wanks TDB of 600°C, oll ore to PPM *Silice to PPM N.A. = No dealysis 3.3. * Balled Sampla

r.S. - Pumped Sample
p - Shortly Prior Te
40 - Prybable Amelysis Server

Part	Sample Ho Of Locality	Date of Sample	발	Totol ^o Dissolved Solide	e Caco ₃	As CaCO,	мо;	cī.	80 ₄ .	Total	Es.*	6*	ca**	Ng.**	90***	Total Cations	611see*	Remorks	Laboratory
Marche	NE-1	4/6/62	7.4	382	2.30		H,4,	1.72	0.89	4.61	3.33	0.85	1.34	0,33	0,1*	6.01	54	ÿ.a.	Namba
	16-1	11/26/63	6,2	262	2.26	0.02	H,A,	1.24	1.12	4.63	2.00	0,16	1.60	0.25	0.07	4.10	58	9.8.	laska
March Marc	N2-1	2/1/64	5,1	363	2,18	0.12	0.04	1.89	1.06	5.29	2.00	0,18	1.54	0,45		6.17	67	9,6.	#.#.4.C.
			7.9	263	1.44	0.02	H,A,	0,62	0, 81	4,09	4.70	0.23	1.34	0.25	0.11	6.63	51		lasks
		97/11/42	6.0	334	2,90	0.26	H,A,	0.76	0.87	4.44	2.17	0.13	1.64	0.61	0.14	4.44	36	7.0.	Nonka
R.	H-2	p8/1/63	7.7	31930	27.40	0,32	F.A.	650.0	74.6	332.13	307.0	0,87	16.00	25.7	0.04	349.61	33	9.6.	Basks
No. 1/10/16 0.1 1300 2.60 2.61 0.91 0.91 0.92 13.09 11.09 0.90 0.90 0.90 0.90 0.90 0.90 11.07 0.91 0.90 0.	11-3	1/30/44	7.9	10826	1.44	0.04	0.03	130.0	26.63	178.14	161.0	2,96	6.43	12.10		1#2.31	,	8.8.	#.#.8,C.
	H-)	95/30/62	7.7	1340	3.17	0.03	H,A,	15.5	3.11	25.15	13,19	8.28	6.04	3.76	C.04	34.31	16	9.6,	Banks
	H-3	1/30/64	6.1	1304	2.04	9.14	0.03	20.8	0 33	33.56	16.50	0.44	3.00	3.24	0.02	21.67	,	8.8.	#.#.#.C.
Process	PH-1	p5/26/63	8,4	1300	3.36	0.02	H,A,	19.6	2.70	34.70	11.81	9.23	5.60	4,03	0.04	21.71	19	8.8.	Neske
	PH-2	93/39/63	7.3	622	6.62	0.12	₽,Α,	2.20	1.62	10.34	3,05	9,23	6.54	0.91	0.04	8.57	3	gas.	Manka
State Printing P	fm-3	p5/26/63	8.2	620	1.40	0.04	H.A.	0.64	1.27	3.35	17.90	9.46	3.33	0.61	6.12	22.50	34	8;8. A*	Manka
Section Sec		p7/19/62	8.1	343	3.%	0,16	11,A,	2.99	1.77	8.60	3.33	0.13	3.89	9.58	9.04	#.17	*	7.8.	Benks
Section P7/19/22 A.1 AST 2.40 0.10 B.A. 2.50 1.80 7.77 2.35 0.31 0.10 0.10 0.11 0.10 1.50 1			8.2	396	2.54	0.16	W,A,	3.21	2.04	7.77	3.21	9.10	4.14	0.83	0.94	8.31	13	7.8.	Stenke
ECR-41 g10722763 H.A. H.A. 2.718 H.A. 2.728 1 H.A. 2.728 1.64 0.73 2.64 1.69 7.777 0.66 0.613 39 Finance Series (Fill 1981) Fill 1			6.1	402	2.40	0,10	E.A.	3,36	1.88	7.77	3.35	0.31	3,94	0.54	0,11	8.19	13	9.8.	Booke
TCR-2: p12*(16/43) 7.8 300 2.00 0.02 R.A. 2148 1.72 3.09 1.09 0.19 3.56 0.58 0.11 3.42 12 Filering Reals (Re.) 1. 772**** While the state of the st	6CR-P	7/16/62	4.5	388	3.68	0.30	₩,A.	2.62	1.41	9.71	3.74	0.23	3.12	0.82	0.11	8.02	46	semple	Bake
Second Column 1/2	ECH-E1	#10/22/63	11,4.	11,4,	2.28		11,4.	3.56	1.64	6.33	3.61	0.09	7.77	0.44		6.13	28	Floring drill bold	Banks
## Bold 17/1/95 8.0 445 2.35 0.02 H.A. 2.42 5.35 8.25 8.25 8.25 8.25 8.26 2.75 H.A. 0.11 7.00 31 H.A. Shahe	PCB-2.	p12/16/43	7.8	300	2,00	0.02	11,4,	2.14	1.71	3.49	1.09	0.18	3.34	0.58	0.11	3.42	12		Henks
Substitution Subs		7/2/63	8.0	443	2,3á	0.02	H,A,	2.02	5.33	8.33	4.33	8.10	2.73	F.41	0.11	7.90	31	B.6.	Manka
State Stat		AT		<u> </u>								<u> </u>						f) ev	
## Sy104/42 7.7 238 2.16 F.A. 0.70 0.56 3.70 4.13 0.10 1.13 7.35 0.56 6.57 76 Ar Smale Partice Maker Entric Name Ent	Olale Week		8.0	342	2.04		B.A.	1.16	1.15	4.31	4.33	5.13	9,60	8,41	0.54	0.47	100	Rehemeral	
Surface Material Coronal Principle Surface Surfa	4		7.7	258	2,14		».A.	0.70	0.86	3.39	4.13	0.10	1.13	7.35	0.86	6.97	74	Ao.	
M.P. 91 91/46/42 7.6 706 1.54 B.A. 9.40 1.54 12.30 3.05 0.72 6.13 0.66 0.56 11.12 6.2 9.8 Banks W.P. 91 11/26/65 7.8 844 1.22 0.62 B.A. 9.59 0.13 V.P. 9.51 0.13 0.76 0.41 0.37 3.56 2.80 0.32 M.66 1. P.6. Banks W.P. 91 1/29/64 8.0 646 1.60 0.12 18.62 1.7: 16.25 5.68 0.41 0.99 3.26 0.01 16.16 50 9.6 9.6 Banks W.P. 92 95/28/67 8.4 9155 10.02 0.13 B.A. 133.57 23.45 131.09 162.2 1.41 0.33 0.16 0.16 0.16 164.18 29 Sample Banks W.P. 92 1/29/64 8.0 9184 0.10 B.A. 10.10 0.00 165.1 130.00 160.20 140.00 0.54 1.36 0.00 0.11 146.23 3 9 Saming Banks W.P. 92 1/29/64 8.0 9184 10.14 B.B. 0 0.06 115.1 23.66 149.72 141.0 3.11 0.30 0.10 244.61 36 Playing Banks W.P. 93 95/28/62 0.9 2330 0.13 0.30 B.A. 13.60 0.02 38.33 4.76 37.13 33.47 1.69 B.O. 0.05 0.00 0.15 14.00 21 16.00 21 16.00 18.00 W.P. 97/11/62 9.4 970 4.54 1.54 B.A. 6.56 2.27 12 1 16.09 0.28 0.20 0.16 0.16 0.16 14.79 4 0.02 14.00 21 16.00 W.P. 97/11/62 9.4 970 4.54 1.54 B.A. 6.56 2.27 12 1 16.09 0.28 0.20 0.16 0.11 16.00 21 16.00 21 16.00 W.P. 97/11/62 9.4 970 4.54 1.54 B.A. 6.56 2.27 12 1 16.09 0.28 0.20 0.16 0.11 16.00 21 16.00 21 16.00 W.P. 6 911/16/65 6.4 740 7.04 0.10 B.A. 6.56 2.27 12 1 16.09 0.28 0.20 0.16 0.16 0.11 16.00 21 16.00 P.B. 6.6 B.A. Banks W.P. 95 910/14/63 6.4 930 3.64 0.10 B.A. 6.56 2.27 12 1 16.09 0.28 0.20 0.16 0.16 0.11 16.00 21 16.00 P.B. 6.6 Banks W.P. 95 910/14/63 6.4 930 3.64 0.16 B.A. 6.56 2.00 16.14 13.90 0.22 0.43 0.16 0.01 16.00 16.77 1 93 P.A. Banks W.P. 95 910/14/63 6.4 930 3.64 0.16 B.A. 6.56 2.00 7.34 93.64 34.00 0.62 1.45 1.07 0.16 57.30 10 P.B. Banks W.P. 95 910/14/63 6.4 930 3.64 0.16 B.A. 6.56 7.00 7.34 93.64 33.00 0.07 2.15 0.91 0.32 97.65 97.9 9.9 9.9 9.9 9.9 9.9 9.9 9.9 9.9 9.	Surface Wat		7.7	233	2,24		F.A.	0.70	0.77	3.71	4.09	0.13	1,20	0.23	8,43	6.10	31	flow samp	
## ## ## ## ## ## ## ## ## ## ## ## ##	W.P. #1	p4/4/42	7.4	704	1.56		H,A,	9.40	1.54	12.30	3.05	0.72	4.15	0.66	9,34	11.12	42	7.0.	Hanke
## N.P. 92 p5/28/67 8.4 9125 10.02 0.13 H.A. 113.3' 23.45 131.09 162.2 1.41 0.23 0.16 0.16 154.18 29 seeple member to the property of the prop	W.P. 91	11/36/63	7.8	844	1.22	0.62	E.A.	9.59	6.13	ν.76	5,61	0.37	3.34	2.80	0.32	14.64	1	P.6.	Books
H.P. 22 910/13/43 6.7 8232 10.86 0.12 H.A. 1090 86.30 140.20 144.0 0.54 1.56 0.08 0.11 146.23 3 91orting Blacks H.P. 22 1/29/64 8.4 9184 10.14 H.80 5.06 145.1 23.66 149.73 141.0 3.11 0.30 0.70 266.61 36 Plowing sample H.P. 63 p5/26/62 8.9 2330 8.13 0.30 H.A. 26.25 5.00 37.37 44.55 0.82 0.05 0.00 0.16 43.46 29 91orting sample H.P. 63 p5/26/64 4.0 7139 4.56 1.44 0.02 34.33 4.74 37.17 33.47 1.49 H.09 9.09 33.34 32 Plowing sample H.P. 64 p11.14/63 6.6 740 7.04 0.10 H.A. 6.96 2.07 17 1 16.03 0.28 0.28 0.16 0.11 16.00 21 8.6. Blacks H.P. 65 p10/14/63 6.6 740 7.04 0.10 H.A. 6.96 2.06 14.14 13.90 0.23 0.43 0.16 0.05 14.79 4 8.R. Blacks H.P. 65 p10/14/63 6.6 3330 3.64 0.16 H.A. 45.00 7.36 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37.9 9.8. Blacks H.P. 65 p10/14/63 6.6 2330 3.64 0.16 H.A. 45.00 7.36 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37.9 9.8. Blacks H.P. 65 p10/14/63 6.6 2330 3.64 0.16 H.A. 45.00 7.36 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37.9 9.8. Blacks H.P. 65 p3/26/64 6.6 2874 5.46 0.92 0.02 43.00 7.57 39.67 32.10 2.36 1.98 1.13 H.01 32.79 14 2.27 34. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.12 H.A. 45.00 7.36 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37. 9.8. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.10 H.A. 45.00 7.36 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37. 9.8. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.10 H.A. 50.00 7.36 39.14 33.00 0.77 2.15 0.91 0.32 37.63 37. 9.8. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.10 H.A. 50.00 7.36 39.14 33.00 0.77 2.15 0.91 0.32 37.63 37. 9.8. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.10 H.A. 50.00 7.36 39.14 33.00 0.77 0.33 0.16 0.11 32.79 14 2.27 34. Blacks H.P. 65 p3/26/62 8.1 2910 4.26 0.10 H.A. 50.00 7.56 39.10 0.97 0.33 0.16 0.11 32.79 14 2.27 31.00 0.00 0.00 0.00 0.00 0.00 0.00 0.0	W.P. #1	1/29/64	8.0	646	1.60	†	0,12	12.62	1.7.	14.35	5.48	0.41	4.99	3,26	0.01	14.18	50	7.0.	H,H. 4,C,
M.P. 62 1/29/64 8.4 9186 10.14 H.80 5.06 115.1 23.65 149.72 141.0 3.11 0.30 0.20 244.61 36 Proving sample Humbs W.P. 63 p5/26/62 8.9 2330 8.13 0.30 H.A. 24.25 5.00 37.37 44.35 0.82 0.80 0.80 0.16 43.46 29 Slowing sample Humbs W.P. 63 1/29/64 6.0 7193 6.56 1.46 0.02 34.33 4.76 37.17 33.47 1.69 H.09 0.09 33.34 32 Proving sample Humbs M.P. 64 p17.16/3 8.6 740 7.04 0.10 H.A. 6.96 2.27 17 1 16.03 0.28 0.20 0.16 0.11 16.00 21 8.6. Humbs W.P. 64 p17.16/3 6.6 740 7.04 0.10 H.A. 6.96 2.00 14.16 13.90 0.23 0.45 0.16 0.05 14.79 4 0.8. Humbs M.P. 65 q10/14/3 6.6 3336 6.32 0.1H H.A. 49.60 8.33 44.33 61.30 0.10 2.85 1.26 0.22 67.71 93 P.6. Humbs M.P. 65 q10/14/3 6.6 3336 3.64 0.16 H.J. 44.95 7.89 34.64 34.00 0.42 1.63 1.07 0.16 37.30 10 P.8. Humbs M.P. 65 p10/14/3 8.5 3340 6.54 0.12 H.A. 45.00 7.34 39.16 33.60 0.77 2.15 0.91 0.32 37.65 37 9.8 Humbs M.P. 65 p3/28/62 8.1 2910 4.26 0.92 0.02 43.60 7.67 39.67 32.10 2.36 1.96 1.13 H.01 32.79 14 Floring Humbs	W.F. #2	p5/28/67	8.4	91.55	10.82	0.13	H.A.	113.3	23.45	131.00	162.2	1.41	0,33	0.16	0.16	164.18	1 27		Meka
H.H. 63 p5/26/62 8.9 2330 8.13 0.3C H.A. 24.25 5.00 37.37 44.53 0.82 8.05 0.80 9.16 53.64 29 Slowing Manks M.P. 63 p5/26/62 8.9 2330 8.13 0.3C H.A. 24.25 5.00 37.37 44.53 0.82 8.05 0.80 9.16 53.64 29 Slowing Manks M.P. 63 p7/11/62 9.4 970 6.54 1.54 H.A. 4.96 2.27 17 16.03 0.78 0.20 0.16 0.11 16.00 21 8.6. Hanks M.P. 64 p11.16/63 6.6 740 7.04 0.10 H.A. 6.96 2.06 14.16 13.90 0.23 0.63 9.16 0.05 14.79 4 8.8. Hanks M.P. 65 4/11/62 7.3 3463 6.32 0.18 H.A. 49.60 8.33 64.33 61.30 3.16 2.15 1.26 0.22 67.71 93 F.6. Hanks M.P. 65 910/14/63 6.6 3330 3.64 0.16 H.A. 49.60 8.33 64.33 61.30 3.16 2.15 1.26 0.22 67.71 93 F.6. Hanks M.P. 65 910/14/63 6.6 3330 3.64 0.16 H.A. 44.95 7.89 58.64 54.00 0.62 1.43 1.07 0.16 57.38 10 F.8. Hanks M.P. 65 11/77/63 8.5 3340 6.34 0.12 H.A. 45.00 7.34 39.14 33.40 0.77 2.13 0.91 0.32 37.63 37 9.8. Hanks M.P. 95 11/28/64 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 32.10 2.96 1.98 1.13 H.0 32.79 14 Flowing Halls M.P. 95 11/28/64 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 32.10 2.96 1.98 1.13 H.0 32.79 14 Flowing Halls M.P. 95 11/28/64 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 32.10 0.97 0.33 0.16 0.11 32.79 14 Flowing Halls M.P. 96 P3/28/62 8.1 2910 4.26 0.10 H.A. 34.10 3.48 4.50 7.31 0.00 0.77 0.33 0.16 0.11 32.79 14 Flowing Halls M.P. 96 P3/28/62 8.1 2910 4.26 0.10 H.A. 34.10 3.48 4.50 7.57 31.00 0.77 0.33 0.16 0.11 32.79 14 Flowing Halls	W.P. #2	910/13/63	6.7	8232	10.00	0,12	F,A,	1090	26,30	140,20	144.0	0.54	1.56	0.56	0.11	144.23	,		lbaks
Hanks	¥.P. #2	1/29/64	8.4	9106	10.14	11.60	5.06	115.1	23,66	149.72	141.0	3.11	0,30	0.26		246.61	36	Floring	8.8.6.C.
N.P. 93 1/29/44 6.0 7193 6.54 1.44 0.02 34.33 6.74 37.17 33.47 1.69 H.09 0.09 33.34 32 Plowing omple N.H.S. N.P. 95 97/11/02 9.4 970 6.54 1.34 H.A. 6.96 2.27 17 16.03 0.28 0.20 0.14 0.11 16.80 21 8.6. Henke N.P. 96 91.16/63 6.6 740 7.04 0.10 H.A. 6.96 2.00 14.16 13.90 0.23 0.43 0.16 0.05 14.79 4 8.8. Henke N.P. 95 4/11/62 7.3 3463 6.32 0.18 H.A. 49.60 8.33 64.33 61.30 3.10 2.85 1.24 0.22 67.71 93 P.6. Henke N.P. 95 910/14/43 6.4 3330 3.64 0.16 H.C. 44.95 7.89 38.64 54.00 0.62 1.43 1.07 0.16 57.30 10 P.8. Henke N.P. 95 11/29/46 8.5 3340 6.54 0.92 H.A. 45.00 7.34 39.14 33.60 0.77 2.13 0.91 0.32 37.63 37 9.8. Henke N.P. 95 17/28/46 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 32.10 2.96 1.98 1.13 H.01 38.07 94 9.0 P.E. Henke N.P. 95 17/28/46 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 32.10 2.96 1.98 1.13 H.01 32.79 14 Plowing Henks	W.P. #3	p5/26/62	8.9	2330	8.13	0,30	₽,A.	24.25	5.00	37.37	44.55	0.82	0.05	0,06	9.16	43.44	29		Manka
H.9. 95 97/11/62 9.4 970 6.34 1.34 H.A. 6.36 2.27 12 1 16.05 0.28 0.20 0.16 0.11 16.00 21 8.6. Manka H.P. 96 911/16/83 6.6 740 7.04 0.10 H.A. 6.36 2.06 14.16 13.80 0.23 0.43 0.16 0.05 14.79 4 0.8 Manka H.9. 95 4/11/62 7.3 3463 6.32 0.18 H.A. 49.60 8.33 64.33 64.33 61.30 3.10 2.43 1.34 0.22 67.71 93 F.6. Manka H.9. 95 910/14/63 6.6 3330 3.64 0.16 H.F. 44.95 7.09 50.64 54.00 0.62 1.43 1.07 0.16 57.30 10 F.8. Manka H.9. 93 11/97/63 8.5 3340 6.74 0.12 H.A. 45.00 7.34 39.14 33.60 0.77 2.15 0.91 0.32 37.63 37 9.8 Manka H.P. 95 1/28/44 6.4 2874 3.44 0.92 0.02 43.60 7.67 39.67 52.10 2.36 1.98 1.13 H.01 50.07 94 9.0 H.E.6 H.9. 95/28/42 8.1 2910 4.26 0.10 H.A. 30.10 3.41 69.87 31.00 0.97 0.33 0.16 0.11 32.79 14 Flowting manks	¥.7. 73	1/24/64	6.0	7193	6,58	1,46	0,02	34.33	4.76	37,17	33,47	1.69	E,09	9.09		33.34	32	Plowing	W.H.S.C.
H.9. #5 4/11/62 7.3 3863 6.32 0.18 H.A. 49.64 8.33 64.33 61.30 3.10 2.85 1.36 0.22 67.71 93 P.6. Banks H.9. #5 910/14/43 6.4 3330 3.64 0.16 H.J. 44.95 7.89 58.64 54.00 0.62 1.43 1.07 0.16 57.30 10 P.8. Banks H.9. #3 11/97/63 8.5 3360 6.54 0.12 H.A. 45.00 7.34 39.14 33.60 0.77 2.15 0.91 0.32 37.63 37 9.8. Banks H.9. #5 3/28/64 6.4 2874 5.44 0.92 0.02 43.60 7.67 59.67 52.10 2.36 1.98 1.13 H.01 58.07 94 9.0. H.E.6 H.9. #6 93/28/62 8.1 2910 4.26 0.10 H.A. 34.10 5.41 69.87 31.00 0.97 0.33 0.16 0.11 32.79 14 Sample Banks	W.9. Ph	97/11/62	9.4	970	6.54	1.54	H,A,	6.96	2.27	17 :	16.05	0.28	0.20	0,16	0,11	16.80	21		Tunks
W.9. #5 910/14/43 6.4 3338 3.64 0.16 H.F. 44.95 7.89 38.64 34.08 0.62 1.43 1.07 0.16 57.38 10 F.8. Blocks W.9. #5 910/14/43 6.5 3340 6.56 0.12 H.A. 45.00 7.34 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37 9.8. Blocks W.P. 95 1/28/44 6.4 2874 5.44 0.92 0.02 45.40 7.47 39.67 32.10 2.34 1.98 1.13 H.01 58.97 94 9.8. H.E.6 W.P. 95 93/28/42 8.1 2910 4.26 0.18 H.A. 30.10 3.41 69.87 31.00 0.97 0.33 0.16 0.11 32.79 14 71.004.08	V.P. 44	p1:,16/63	6.6	740	7.04	0,10	H.A.	6.76	2.06	14.16	13.90	0.23	0.43	0-16	0.03	14.79	•	0.8.	Books
H.9. #3 11/97/63 8.5 3340 6.54 0.12 H.A. 45.00 7.34 39.14 33.40 0.77 2.15 0.91 0.32 37.63 37 9.5. Monks H.P. 95 1/28/64 6.4 2874 5.44 0.92 0.02 43.40 7.67 59.67 52.10 2.36 1.98 1.13 H.91 58.07 94 9.6. H.E.6 H.9. #6 93/28/62 8.1 2910 4.26 0.10 H.A. 34.10 5.41 69.87 31.00 0.97 0.33 0.16 0.11 32.79 14 Firsting massle	W.9, #5	4/11/62	7.3	3863	6.32	0.18	H.A.	49.60	8.33	44.33	61.50	3.18	2.45	1.26	0,22	67.71	93	7.6,	Stanto
W.P. 95 1/28/64 6.4 2874 5.46 0.92 0.02 43.60 7.67 59.67 52.10 2.36 1.98 1.13 H.01 58.07 94 9.8. H.E.6 W.P. 95 1/28/62 8.1 2910 4.26 0.10 H.A. 30.10 3.61 69.87 31.00 0.97 0.33 0.16 0.11 32.79 14 31.00 manual man	W.9. #5	910/14/43	6.4	3330	3.64	0,16	Mai .	44.95	7.89	58.64	34.00	0.62	1.43	1.07	0.16	57.30	10	7.4.	Broke
W.9. 06 p3/28/62 8.1 2910 4.26 0.10 H.A. 30.10 3.41 69.07 31.00 0.97 0.33 0.16 0.11 32.79 14 2 comple maks	W.9, #3	11/97/63	8.5	3340	6.06	0,12	H.A.	45,00	7.34	39.14	33,40	0.77	2.15	9.91	0.32	37.63	37	9,5,	Rooks
	W.P. 95	1/28/64	6.4	2874	5,46	0.92	0.02	43.40	7.67	59.67	32.10	2.96	1.78	1.13	IF.01	58.07	94	9.8.	B.E.6.C.
	W.9. #6	p3/28/62	0.1	2910	4.26	9,10	3. A.	30.10	3.41	69.87	31.00	0,97	0.33	0.16	0.11	32.79	14	sample	Sheks
	W.9. #4	910/13/63	8.8	2395	6.20	0,20	₽,Α,	54.73	3.35	44.54	33.13	0.30	1.54	0.00	0.04	33.20	13		Tonks

								APPR	K UX G. C	ont.								
Bample Po. er Locality	Date of Sample	pä	Tetal ^e Disselved Solids	As Cacco	As Carons	wo,	cı.	80 <u>.</u> "	Tetel Antons	Ka*	r.	Ca**	Na**	Pa***	Totel Cetlons	Silice*	S-marks	Laboretory
W.P. #6	1/28/64	ę ·	3098	3,06	0,34	0.18	38,0	5.06	49.46	49.15	. 16	0.49	0.50		57.50	78	Plowing Sample	B.N.8.C.
W.P. 87	p5/28/62	7.7	5170	6,54	0.14	N.A.	41.1	7.10	54.68	50.6	1,90	3.64	0.82	0.16	57.12	7	*lowing Sample	Henke
W.P. 07	10/15/63	8.2	3010	4 , 84	0.04	N.A.	39.8	7,41	52-29	46.8	0,21	3 50	0.82	0.1i	31.44	24	Plowing Sample	Henke
W.P. #8	p3/28/42	8.5	3660	14.40	0.30	N.A.	66.7	12.21	95.61	114.0	1.60	0.25	0,41	0.11	116.57	2	7.4.	Manke
V.P. #9	p5/28/62	1.7	3115	9,44	0.24	F.A.	31.3	9.40	50.62	54.9	0.31	C.05	0.00	0.05	45.39		P.S.	Renke
V.P. 99	p2/24/64	9.8	2649	9,42	0,28	H.A.	30.0	9.54	49.24	44.8	0.51	1.80	0.08	0.22	47.41	17	P.8,	Hanke
W.P. #10	p 3/28/62	8.7	4820	8,46	C.24	B.A.	60,9	16,30	79.90	87,8	2,44	0.05	0.06	0.16	90.53	46	2.8.	Kanke
W.P. 830	11/26/63	1.6	→220	8,92	0.18	H.A.	56,7	9,34	75.34	71.1	0,54	1.54	0.00	0.11	73.37	10	7.5.	Hanks
W.P. #10	12/16/63	8.8	4034	7.48	0.12	H.A.	55.0	8.70	73.30	70.1	0,51	0.45	0.33	0.11	71.30	1	P,8,	Hanks
W.P. #10	1/28/64	8,8	4371	7.48	1.38	0.03	50.6	8.95	74,44	75.25	3.07	0.15	0.15	0.01	78.89	49	7.8.	H.B.S.C.
W.P. #11	p7/11/62	9.5	35150	65.80	79.60	₩.Α.	359,0	73.9	578.30	421,0	0,47	0.25	0.15	0.16	422,24	51	Plowing Sample	Hanks
W.P. 811	1/30/64	9.8	36562	82,5	275.0	0.04	568.1	73.2	798.1	474.8	25.5E	0.05	0.04	0.01	200.5	70	Plowing Sample	N,B,B,C.
W.*. 812	11/26/63	8.0	1960	1,96	0 02	N.A.	27.5	4.10	33,58	27	0.13	4.59	0.41	0.11	32.84	17	P.6.	Reske
W.P. #12	1/28/84	8.0	1974	1.84		0.24	28,45	3.85	34.40	25.02	1.23	4,54	0.52	0.01	29.13	5*	P.8,	H.W.R.C.
W.P. #13	p8/1/62	8.6	775	10,90	9.6	P.A.	1.30	2,59	24.19	12.2	0,23	0.50	0.99	0.11	14.03	42	P.S.	Manke
W.P. #13	p10/16/63	8.7	1770	8,04	0.16	N.A.	20.20	3,66	54,04	16.4	0.18	0,20	0.16	0,05	16,99	•	P.S.	Resta
W.P. #13	11/27/63	8.4	304	8.42	6.18	B.A.	0.56	1,06	10.42	3.30	0,15	2.30	0.91	0.01	8.87	•	P.S.	Hank o
W.P. #13	1/28/64	8.2	696	9,80	0.44	0.02	0.42	1.00	11.88	7.04	0.56	1.52	1.+8	ļ <u>.</u>	11.42	54	P.S.	N.N.S.C.
W.P. 814	p8/1/42	8.5	31 20	21.80	1.58	H.A.	36,4	0.12	60.20	60.0	9,82	0.10	0.91	0.11	41.%	54	P.S.	Kanke
W.P. #14	p10/16/63	9.5	4647	25,08	1.17	H.A.	63.0	0.55	89.33	80.1	0.51	5.79	9.33	0.27	85.00	11	P.8,	Renke
W.P. 814	1/28/64	8.5	4960	23.18	7.56	0.0z	42.1	0.02	87.66	87,00	2.17	0.24	0.87	0.51	90.29	53	P.S.	B.H. 8.C.
W.P. #15	p8/1/62 4/1/62	7.4	200	2.32	0.50	H.A.	7.92	0,19	18.41	14.80	0,41	G. 15	0,38	0,11	16.03 3,84	47 50	P.3.	Hanke Heake
V.P. 817	4/6/62	7.4	918	7,82	0,02	H.A.	4,00		-	20,65	0.95	<u> </u>	0.53	0.52	22.75	50	P.S.	
V.F. 818	p8/1/62	8.3	990	9,50	C, 68	N.A.	3.70	3.84	15.72	15.00	0.46	0.50	0.33	0.05	16.21	74:	A* P.S.	Hanke Sanke
V.P. #18	910/14/63	8,5	1096	8.36	0,12	3.5	3.64	8,12	22.24	17,75	0,26	1,80	0.13	0.11	20,25	40	P.S.	Feeke
V.P. #18	11/26/45	8.6	644	8,78	0.14	N.A.	2,42	3,73	15.07	J.73	0.26	2,19	0.14	9.03	13.39	14	7,8,	Banka
V.P. #18	1/30/64		1014	8,44	0.22	0.01	5,58		16.27	14.80	0.26	0.48	0.27	0,01	15.02	65	P,5,	H,H,8.C.
W.P. #19	NO SAMPL	1	<u> </u>	•		 											Inecceptik	
W.P. #21	NO SANGE					-			1								ineccessibl	
W.P. #22	7/24/63		382	3.12	0.00	P.A.	1.50	5,59	10.47	3.39	0.28	3,45	0,49	0.14	9.75	20	to sample	Recks
V.P. #22	11/27/63	 	399	5.44	0,64	₽,٨,	1.75	5.55	11.02	4.70	0,34	2.44	0.58	0.05	10.13	22	P.s.	Henks
W.P. #22	1/29/64	8.1	674	3.24		0.01	1.50	5.56	10.41	5.25	0,24	3.78	0.67		7,34	46	P.8,	B,B,8,C.
W.P. 823A	p/8/1/42	7.4	44.0	3.72	0.04	H.A.	2,00	2.31	8.07	5.83	0.20	2,49	0,74	0.11	7.57	45	P.5.	flenke
W.P. #23A	910/15/43	8.2	ш.	2,97	0.04	F,A,	1,55	3,21	7.52	2,22	0.00	4,5*	0,74	0,11	7.54	29	P.S.	Senka
W.P. #23A	11/27/63	8.2	571	1.72	0.18	٧.٨.	1,66	2,42	5.48	1,83	0.18	2,74	0.59	0.61	5,25	75	P.S.	Kenke
W.P. 823A	1/29/64	7.8	384	2.52		0,15	1.4-	2.21	4.52	3,04	0,26	2.20	0.42		4.12	36	P.S.	и,и,5.с
W.P. #258	11/23/63	#.0	809	4,44	3,02	N.A.	5.11	5.27	14.84	9.78	0.41	2.79	0.74	0.05	13.77	10	S.S. New Well Adj 23A	
W.P. #238	1/29/64	7.9	369	2.52		0.03	1.24	4.21	8,00	4,26	0.20	2.50	0.73	•••	7.69	18	8,9,	B,8,5,C.
W.P. #74	p5/28/62	8,2	334	2.34	0.02	P.A.	2,00	1.21	5.47	4,05	0.15	0.80	0.00	0.14	7.".	29	P.4.	Hanbe
,W.T. #24	1/30/64	7.9	343	2,22	-	0.06	2.20	1.21	5.49	4.52	Ü, 16	0.67	0.80		0.15	23	7.8.	W.W.S.C.
	<u> </u>		<u> </u>		1	ــــــــــــــــــــــــــــــــــــــ			<u> </u>	n	L	i			H			

Sample He er Locality	Date of Sample	pil	Total ⁹ Oleselvad Solids	As Caco,	۸ه ۵۳۰ ش	жо,	ď.	BO ₄ "	Yotal Aniens	Na*	R+	Cs**	Ne**	,.···	Total Cations	ML) (ca*	Remarks	Laboratory
W.P. #25	p3/28/42	8.2	302	1.84	0.02	W.A.	0.96	1.50	4.40	4.78	0,13	1.43	0.08	0.11	6.53	40	P.8.	Monke
¥.P. #26	p7/11/62	7,9	3995	2.50	0.06	Ħ,A,	30,73	34.05	69.38	2.39	0.06	47.43	8,86	0.05	38.83	•	Seepe ge Pood 4*	Manks
W.P. #26	p7/11/42	8.3	1010	2.86	0.02	8,4,	31.40	36,05	70.33	19,35	0.29	41,60	8.88	0,11	70.73	6	Sospage Tond	Manka
W.P. #24	p10/13/63	8.0	3619	1.28		N.A.	45,30	43.95	92 33	19.50	0.44	58.20	11.74	0.23	90.13	•	Sospage Poné	in she
W.P. #27	11/27/63	8,3	778	3.56	0,04	M.A.	2.71	7.86	14.21	2,96	0,20	6,23	3.%	0.03	13.43	13	P.S.	Backs
W.P. #28	NO AMALYS	28 AVAI	AME														lunccessi to Semple	blo.
W.P. #29	8/1/63	8.4	210	2,36	0.12	8,4.	1.94	0.38	4.92	0.26	0.03	2.34	1.64	0,11	4.38	4	690page	lineks
W.P. #30	p8/1/62	8.0	643	6.90	0.00	B,A.	2.31	1.63	11.32	3.74	0.31	4.74	1.13	0.03	9,99	•	Soupage	Page
W.P. #30	7/31/63	9.1	344	1.24	C.06	H,A.	2.34	₹.23	6.09	2.87	0,25	1.35	9.86	0.16	14.67	il	Sampage 4*	Tenke
W.F. #31	p3/28/62	7.9	347	2,86		11,4,	1.61	1.90	6.37	4,63	0,31	2,42	0.38	8,11	8.07	39	7.8.	
							<u> </u>						 				A*	Reske
6.P. #31	p10/15/63	8,2	320	2.76	0.04	8,8.	1.58	2,42	6,80	2,92	0,28	2.24	0.66	0.05	6.13	•	7.8.	Nanke
W.P. #31	11/26/63	8.2	302	2,64	0.04	8,8,	1.38	2.10	6.34	3.00	0.13	2.24	0.33	0.03	3.77	•	7.6.	Rauka
W.P. #11	1/29/64	7.9	421	2.66		0,00	1.35	3.83	7.82	3.26	0.28	1.83	0,49	•	3.88	34	P.S. 46	E.W.6,C,
.t.P. #32	p8/1/62	7.9	200	3.24	0.02	H,A,	0.71	0.42	4.39	1.70	0.18	1.40	0.41	0.11	3.80	ນ	Soopaga	lineko
W.P. #32	p10/16/63	8.0	90	7,86	0.02	8,4.	0,28	0.19	2.35	0,48	0.03	1.20	0.23	0.03	2.01	•	Suspage	Manks
W.P. #33	p8/1/62	b.6	643	6.30	0.48	¥,4.	2.24	3,11	11.13	10.41	0.00	0.05	0.16	0,11	10.61	30	7.5.	Hooks
W.P. #33	913/13/63	8.4	1025	3.56	9.00	8,4.	4.74	8,20	18.60	13.70	0.23	2 99	0.47	8,11	17.32	32	2,8,	Make
W.P. #33	11/27/63	8.5	730	4.84	0.18	H.A.	2.14	6.66	13.82	10.70	0.31	1.69	0.06	0.11	22,69		P.8.	Hanks
W.F. 233	1/28/64 p12/16/63	8,1	319	3.72 6.32	0,04	0.01 M.A.	0.93 89.43	1.90	7,10	93.43	0.22 0.74	0.09	1.32	0,20	96,65	3	P.H.	H,H,B,G,
W.P. #33	NO ARALYN				1.4				- 77.77	73.43		-			7		Inscessi	10
												_	 				Ineccessi	
w.r. #34	NO AMALTS	LI AVAI	TABLE										ļ				te sample	
₩.P. #37	1/28/64	8.2	6385	7,14	1.12	0.04	112.1	14.7	133,12	95.3	4,21	0.71	2.46		102,86	58	P.S. A0	M.M.R.C.
V,P. /34	NO ARALYS	ES 49AE	TYK's														inoccessi te sample	
W.P. #39	p12/16/63	8.3	1364	2,24	0,02	H,A,	10.20	8,24	20.70	16,96	0,46	2,76	0.06	0.16	20.42	99	floring semple	Hanks
Lee Not Spring	p12/16/63	8,3	1563	2.06	0,02	W.4.	11.91	8.43	23.64	19.64	3.02	2.34	0.00	9.03	25.13	124	7lowing comple	Tenks
W.P. #40	9/26/63	8.7	377	2,16	0.02	8,6.	2.63	2.08	6.89	1.83	0,20	4.94	0.23	C. 03	6.37	•	Floring same	Rentu
W.P. MO	21/27/43	8,2	254	2,26	0,04	H,A,	1.47	2.62	6.39	0.74	0,13	3.39	0, 23	0.11	4.84	7	Flowing comple A*	Menke
Windmill 4 mi. west of W.P. 37	11/26/63	8,8	18384	13.60	0.46	11,3,	166.30	20,38	200,76	177.2	C.61	1.25	9,16	Q, 12	179.33	26	2.8.	Bouko
Schoolite	p17/16/63	H,A,	904	2.26	0.02	B.A.	3.86	6.45	14.39	11,19	0,23	2,49	9.00	0.05	14.0	20	2.8.	Maske
34-1	11/27/63	8.0	196	1.32	0.02	8,8,	0.66	2,21	3.43	1.4	0.10	1.80	0.33	0.05	3.30	,	0.5,	Souks.
9Y-1	p12/16/63	Ħ,A,	276	1.30		H,A.	0.66	1.23	3.23	1.22	0.08	1.33	0.00	0.05	2.98	,	0.8,	lanks.
DA-3	p12/26/63	8.6	464	4.08	0.02	8,4,	2.14	3.44	9,60	4.39	0,13	2,54	1.36	0.11	8.73	1	2.8.	Tooks
DV-3	11/27/65	8.2	231	2,12	0.02	H,A.	1.35	1.53	4.94	2,75	0.18	1,89	0.16	0.11	3.00	,	0.0.	Baks
DV-3	11/27/63	8.0	272	1.72	0.04	H,A,	1,41	1.33	4.52	2.56	0,06	0.93	0,16	0.03	4.20	14	5,6.	Banks
pr-4	p12/16/63	6,0	293			8,8.	0.99	1.77	2,76	1.44	0.15	1.40	0.23	0.05	3,29	18	3,5,	Beite
DV-9	p12/16/63	8.3	204	1,54	0,04	B.A.	1.11	1.19	3.50	1.17	0.13	1.63	0.23	0.05	3.43	14	8.8.	Broke
Selt Parm No. 1	p12/16/63	9.3	341648	690.20	69.80	8,4,	4800	776.0	6358,00	6000	1.43	7.00	0.90	0,11	5004,44	,	Soopage	Manke
Salt Perm No. 2	212/16/43	9.3	360600	727.29	70.00	8,4,	3010	806.0	9614, 9 0	6360	1.13	1,50	0.66	0.11	6363.37	2	Seepage	Backs

APPENDIX H

Well Hydrographs Constructed on the Basis of Periodic Measurements

Measurements are in feet from established reference points which are, in most cases, slightly above ground level. The hydrographs indicate trends in water levels on the basis of indicated measurements. Hydrographs for H-2, H-3, and H-4, as well as the barographs, have been constructed by plotting the readings obtained at 2:00 PM each day.

110.90

111.00

111.10

110.80

309.

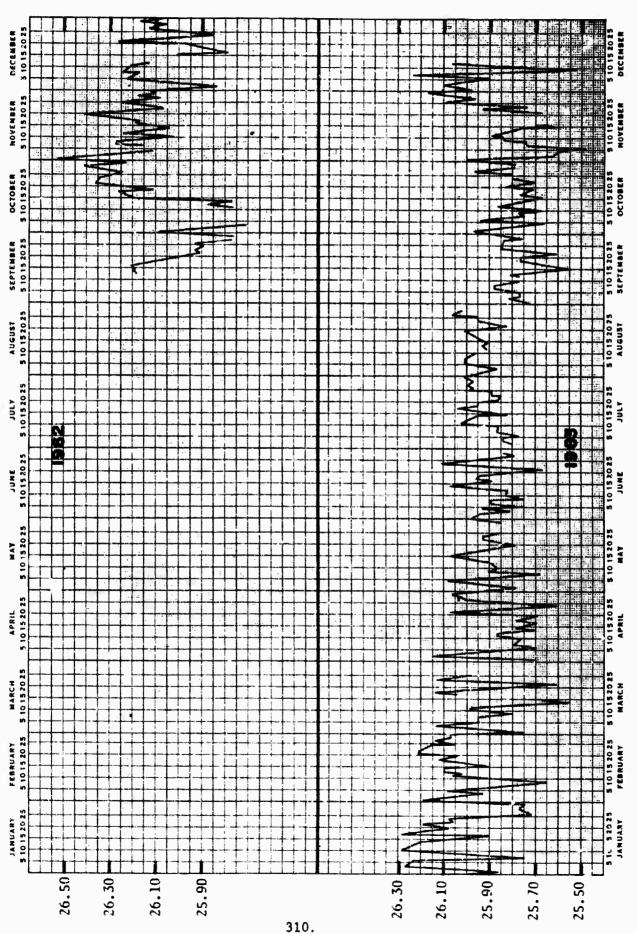
110.80

111.00

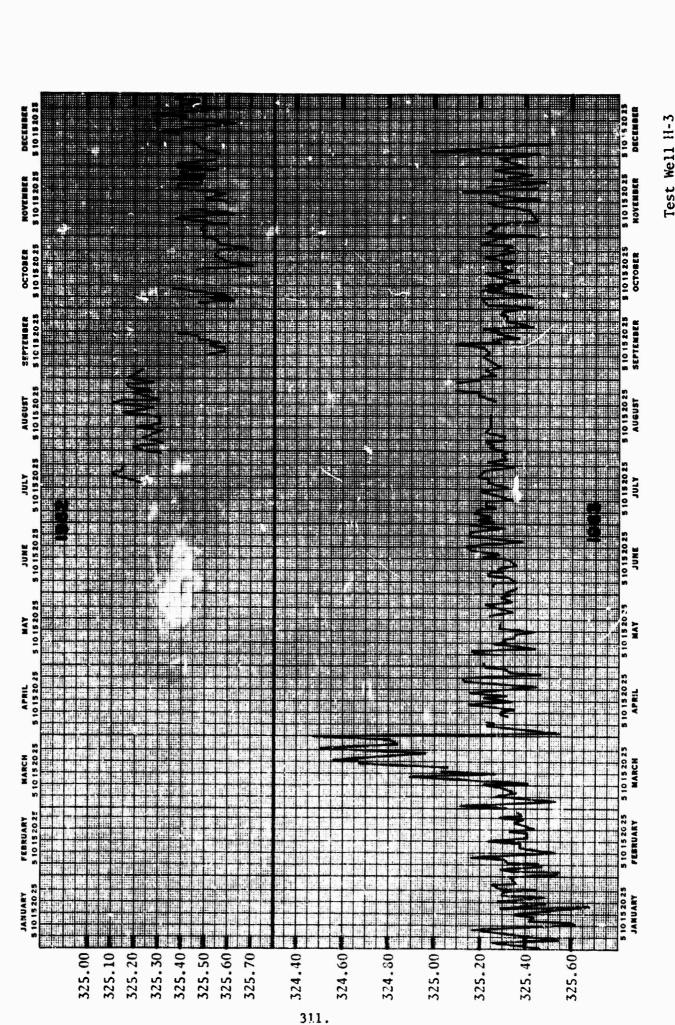
111.10

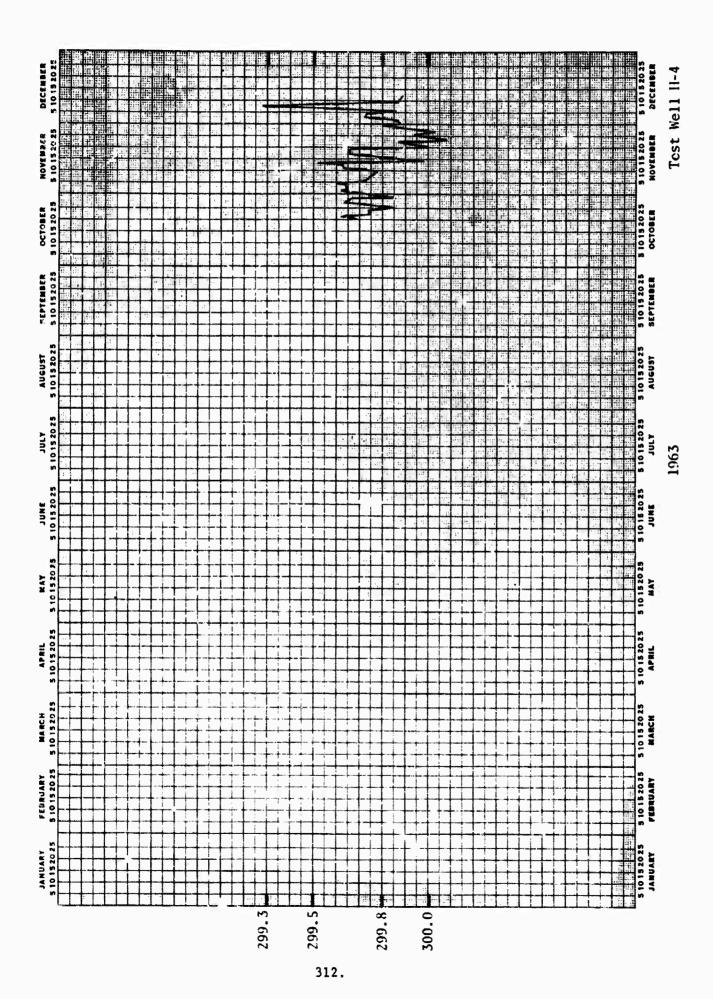
110.90

Test Well H-2

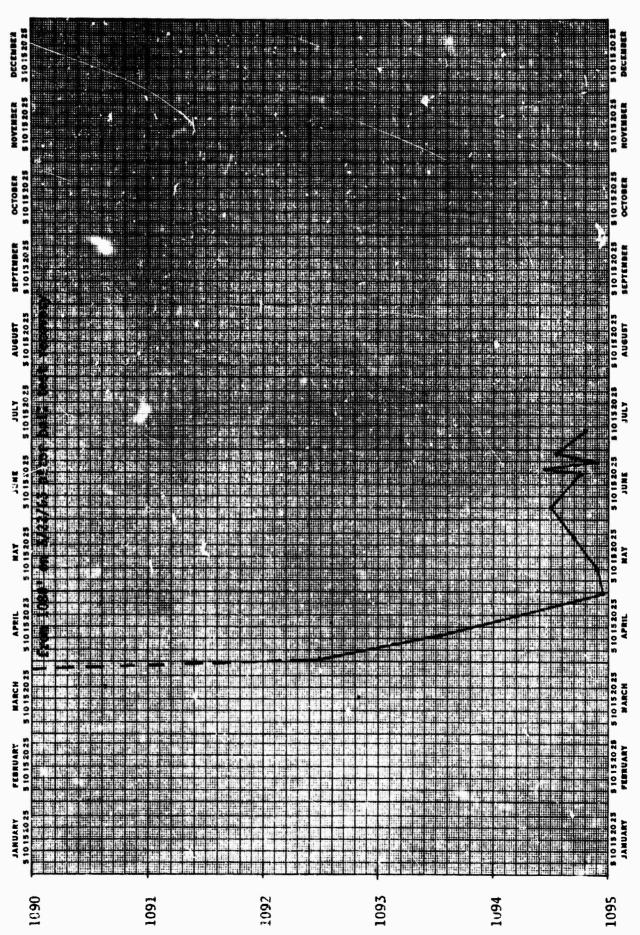


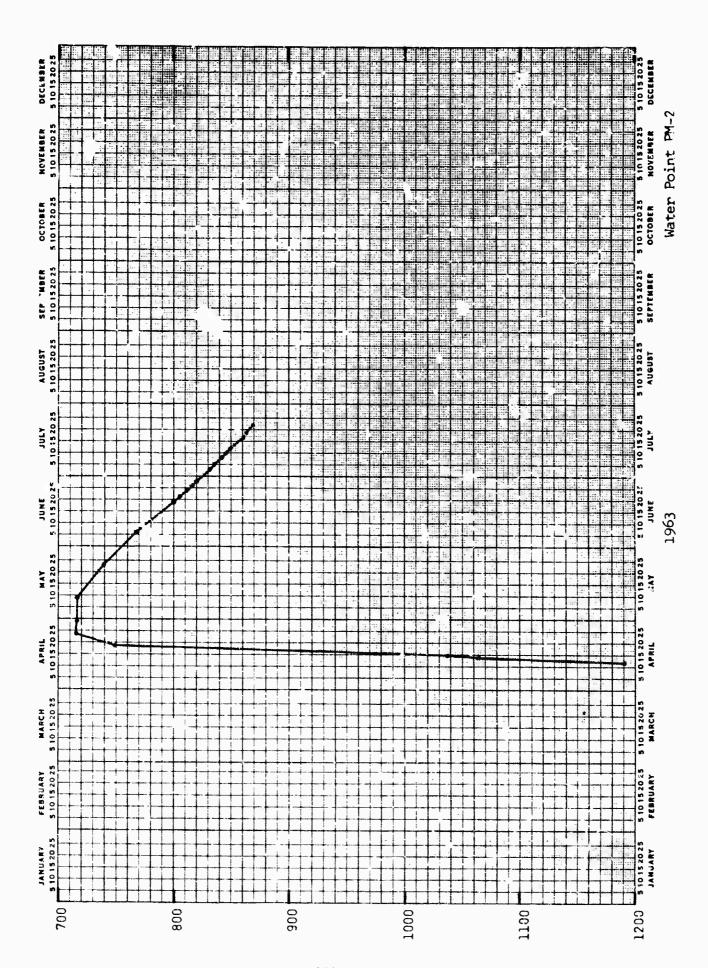
Barometric Curve at N.P. H-2



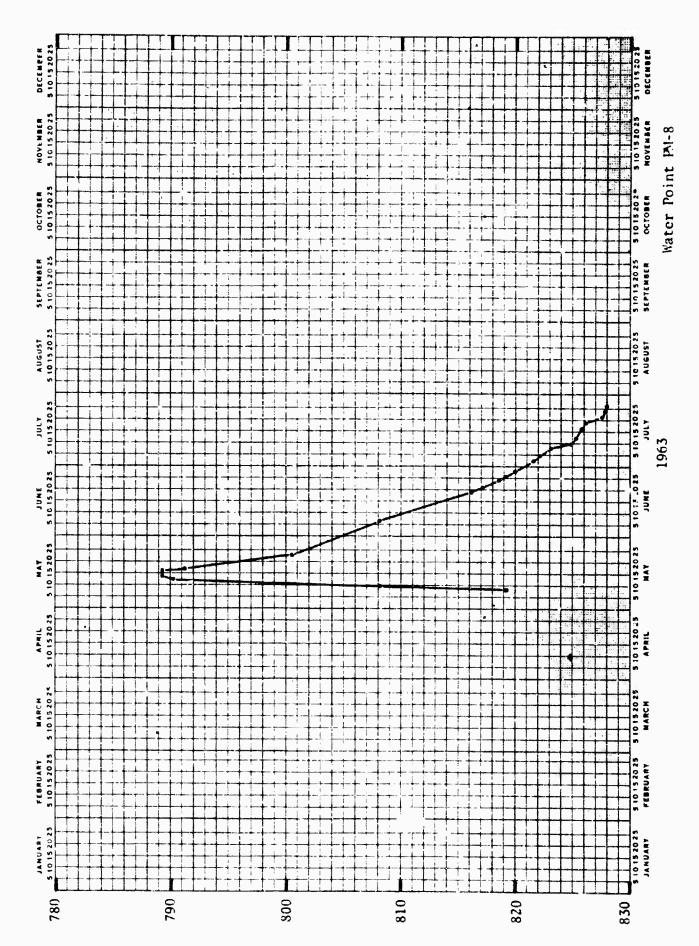


#



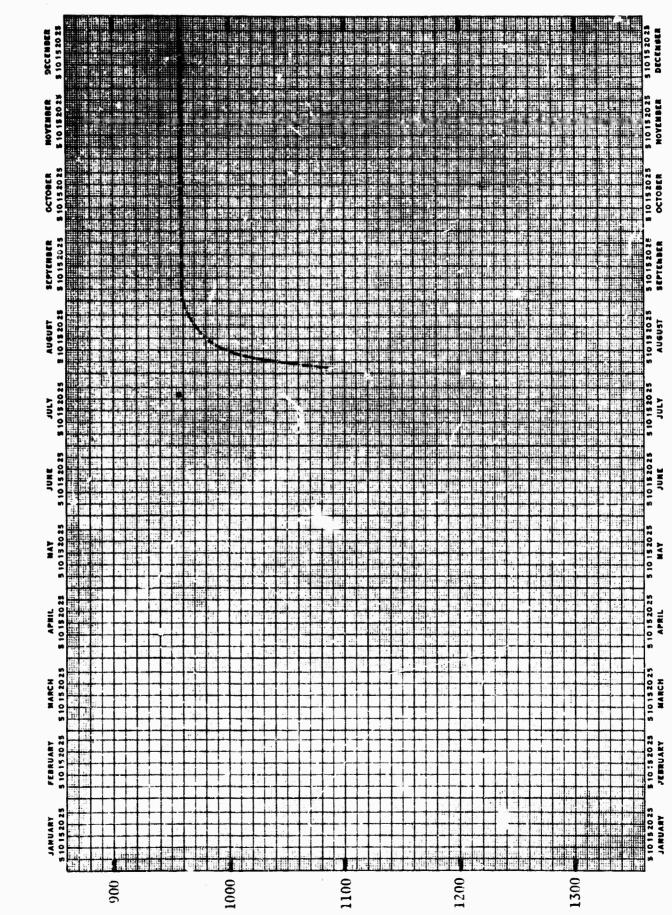


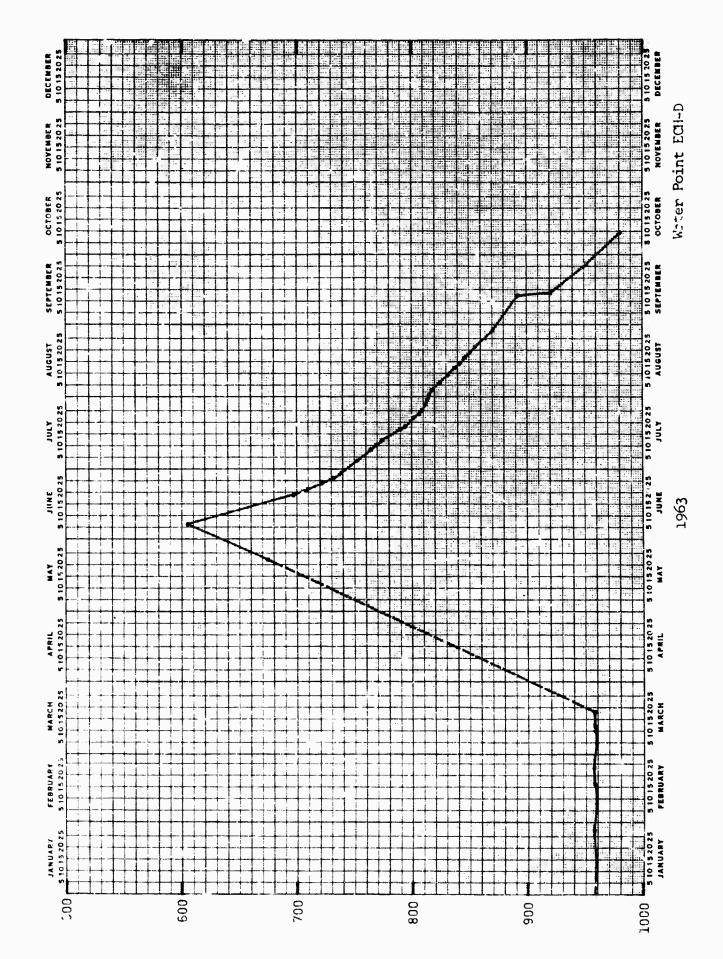
315.



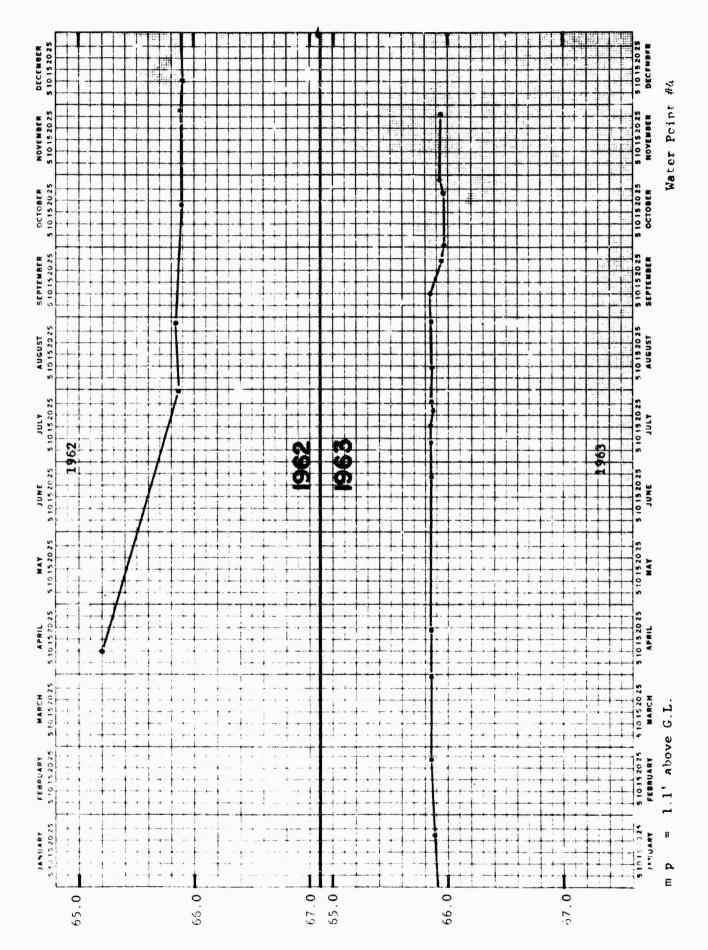


The state of the s

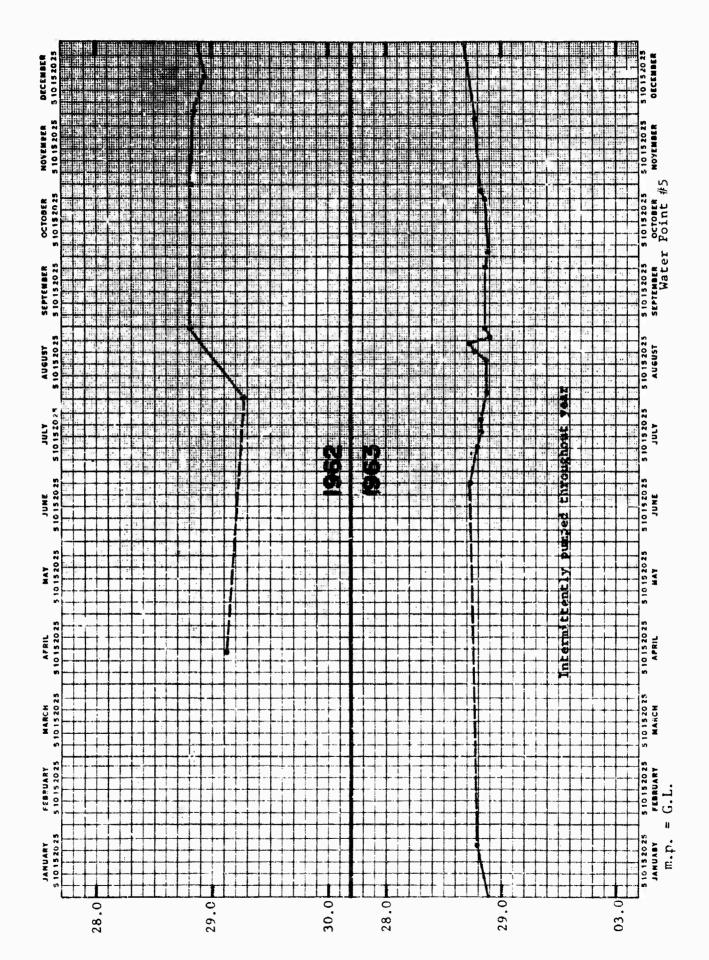


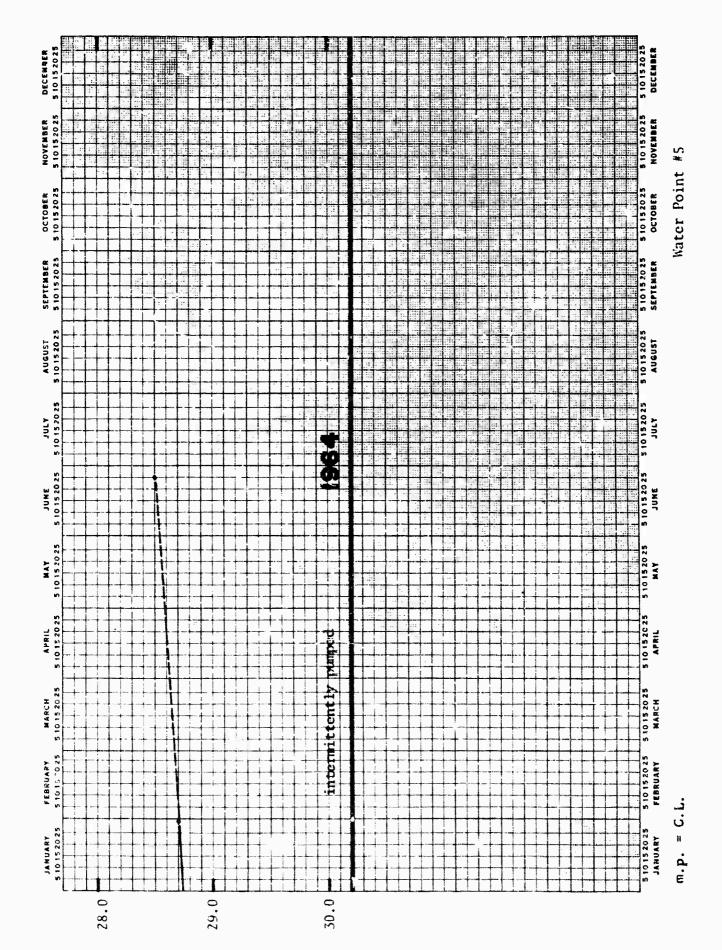


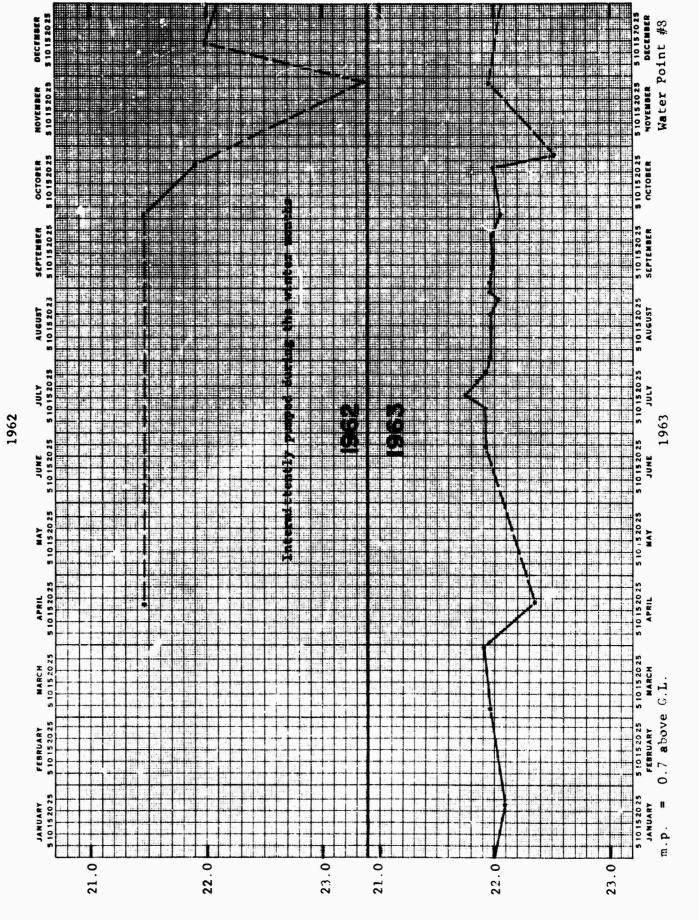
1' below G.L. 11 m.p.

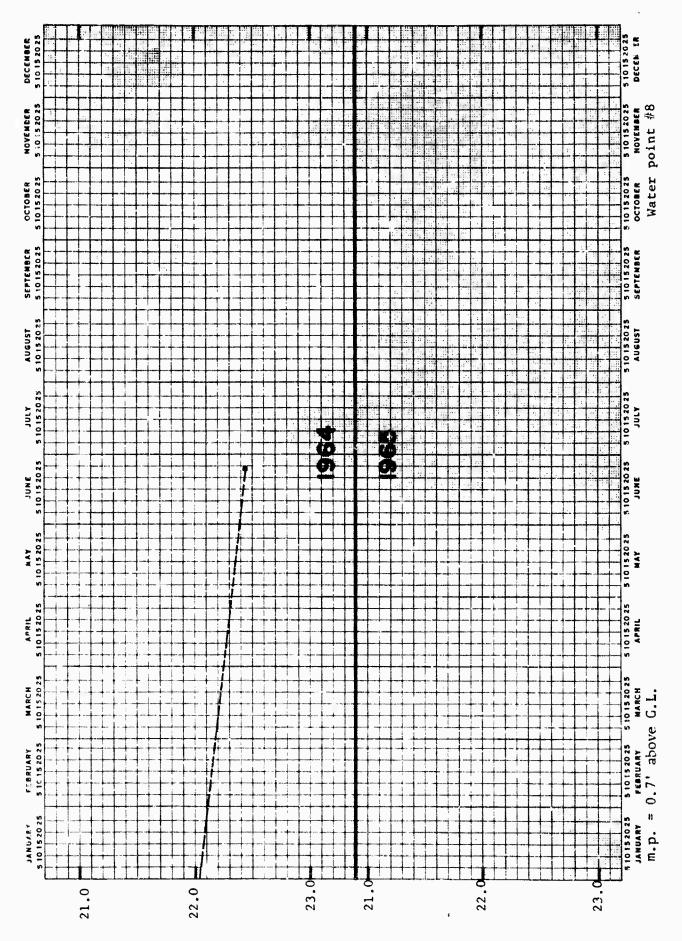


320.









31.0

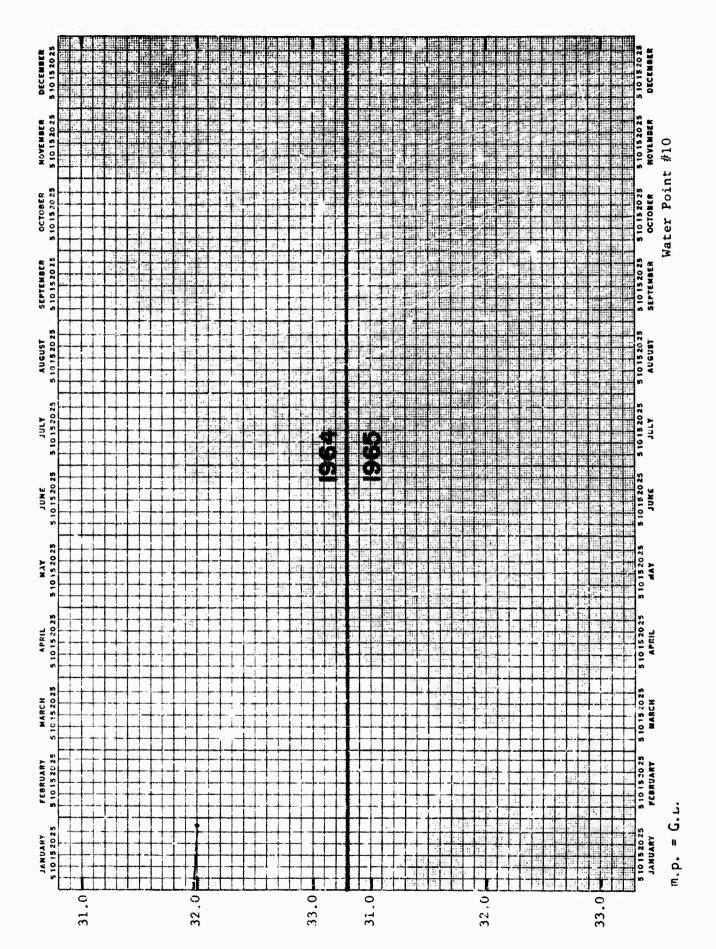
Ç

3

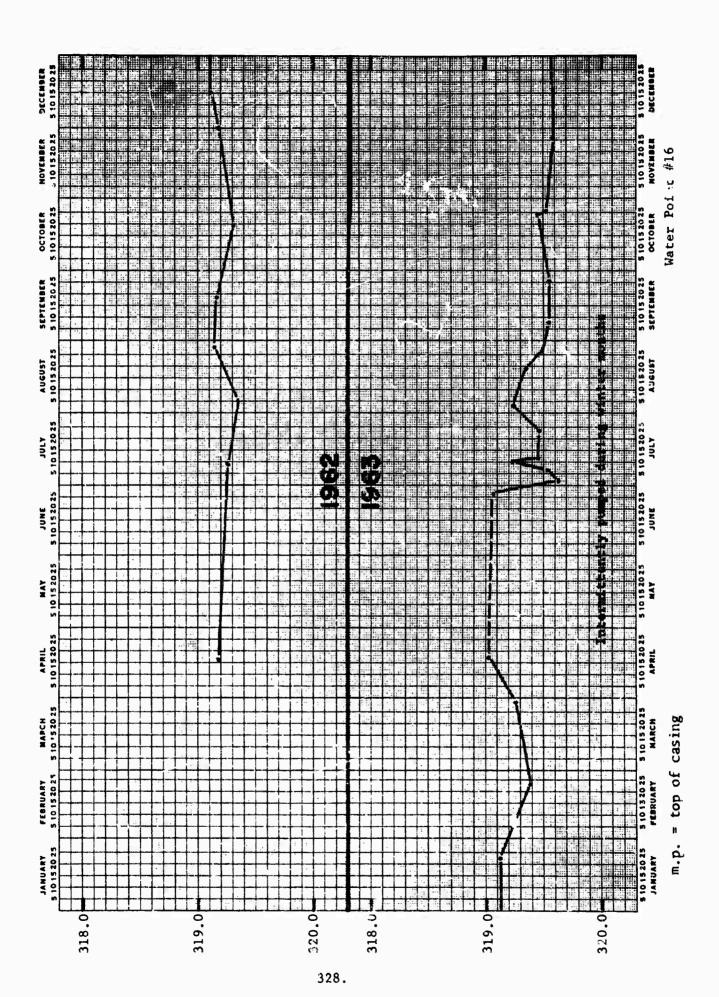
33.0

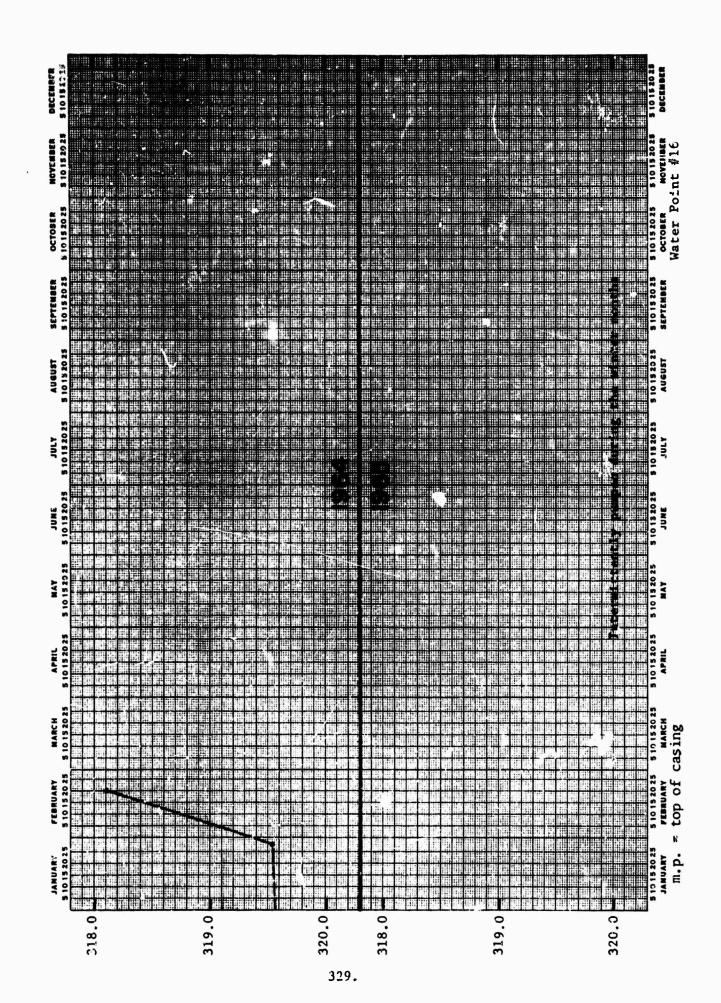
32.0

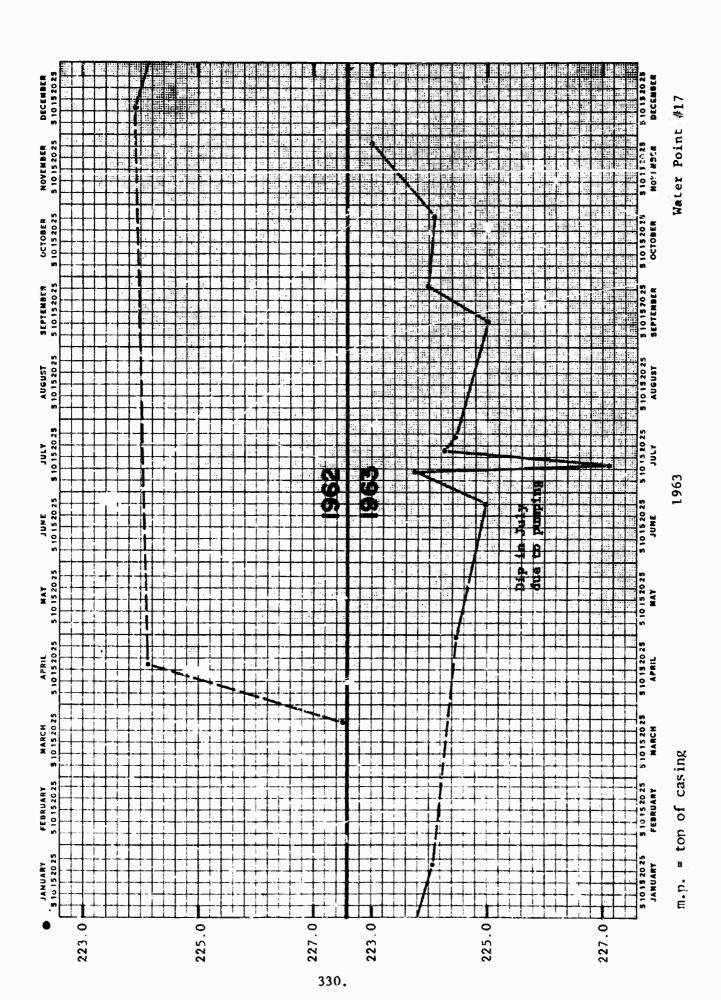
31.0

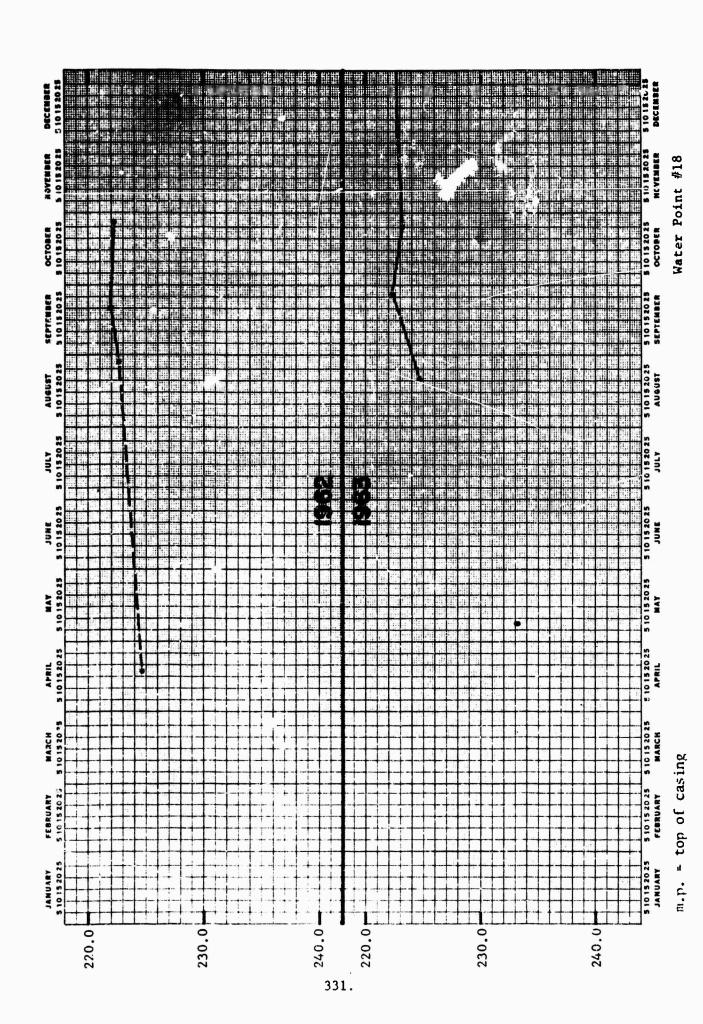




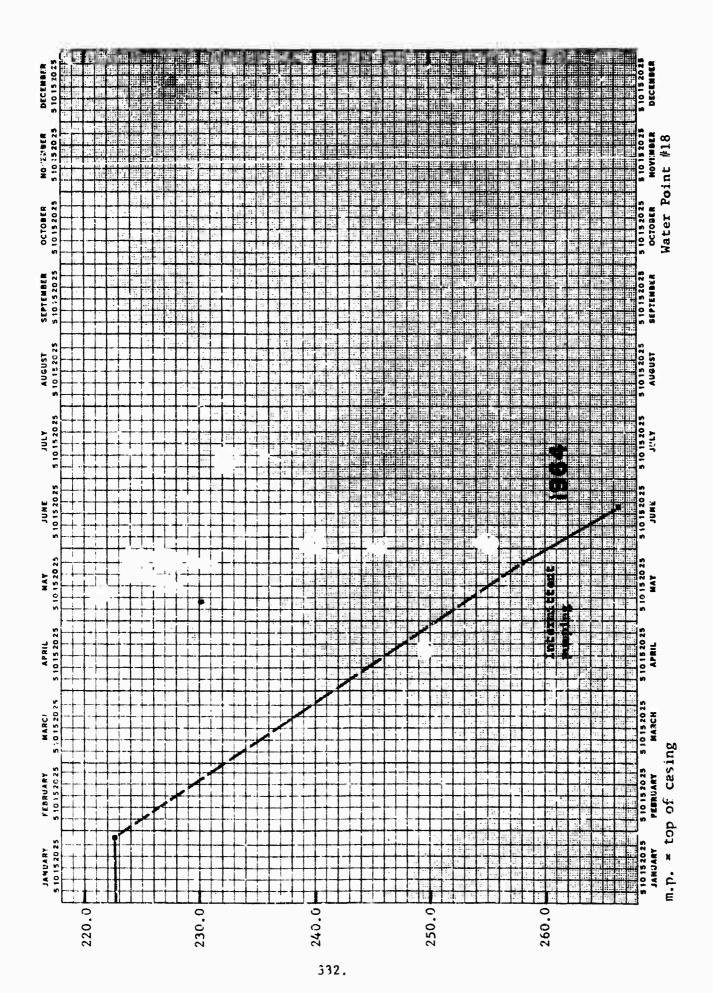


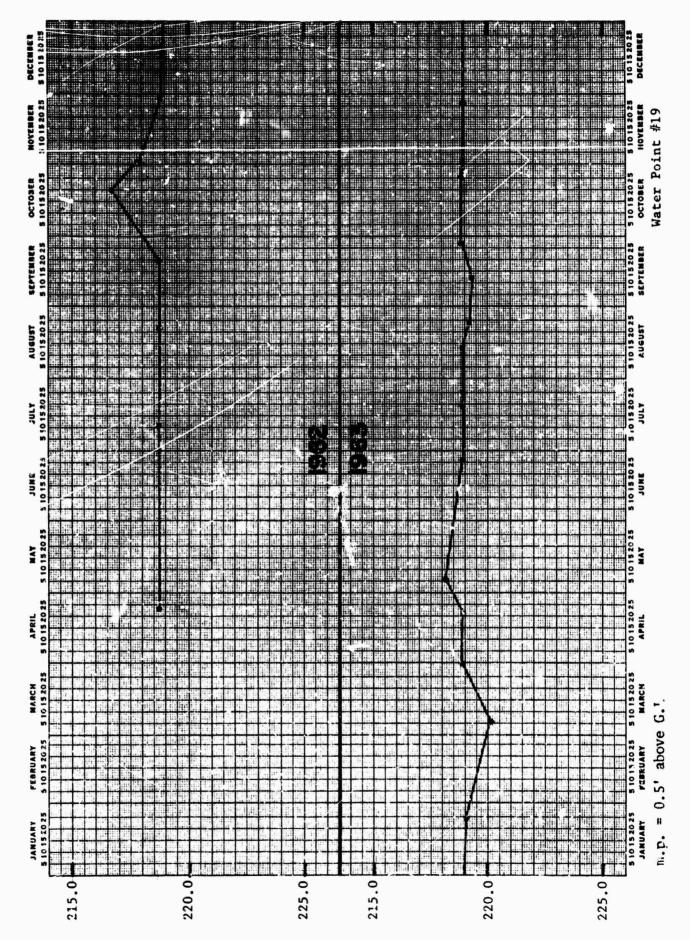






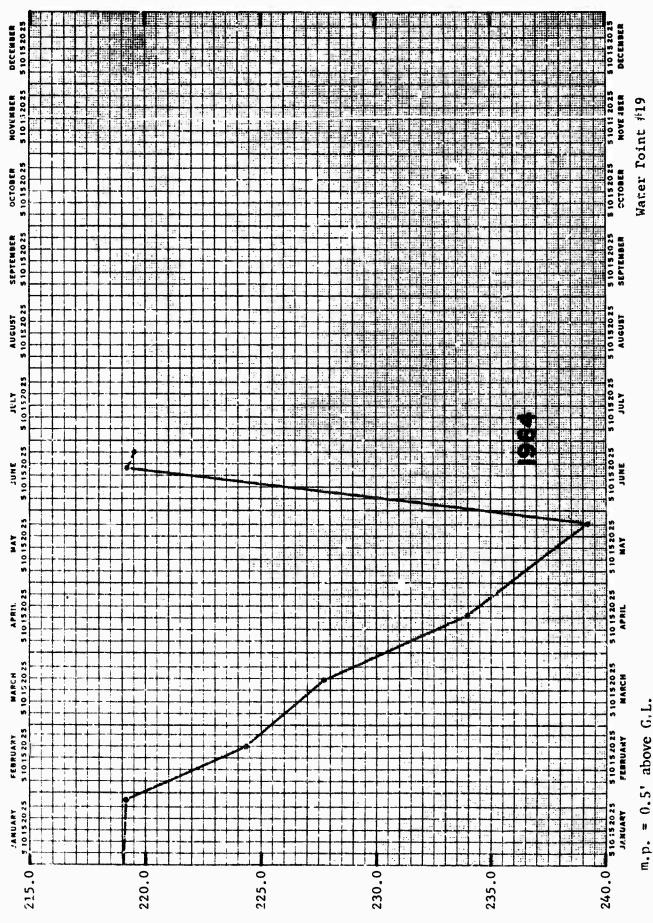
THE RESERVE OF THE PARTY OF THE



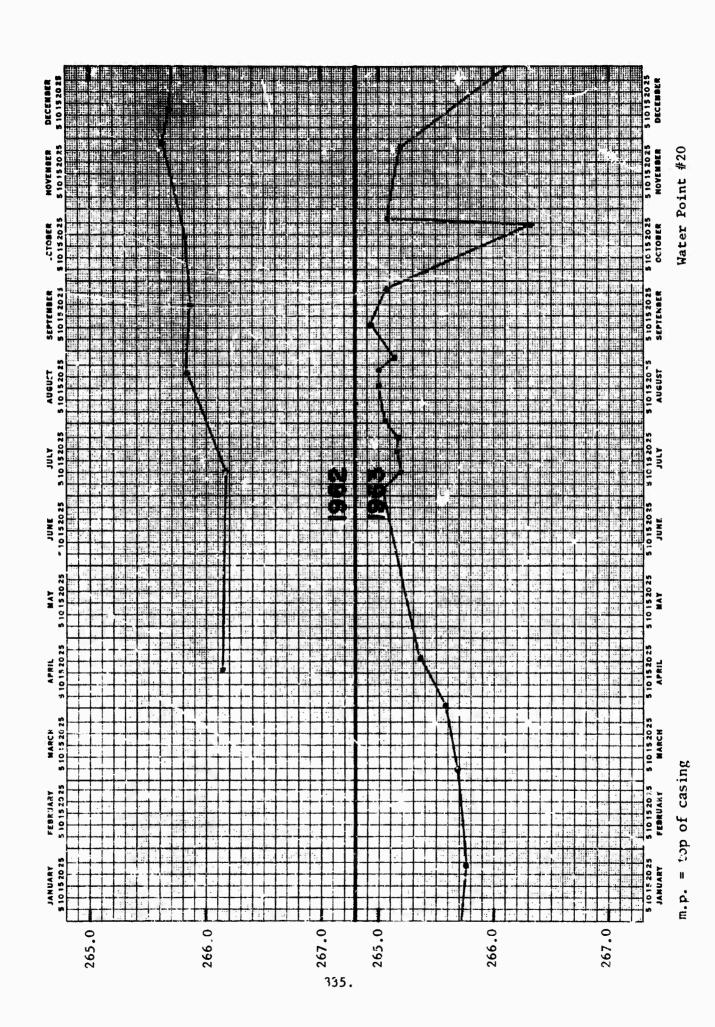


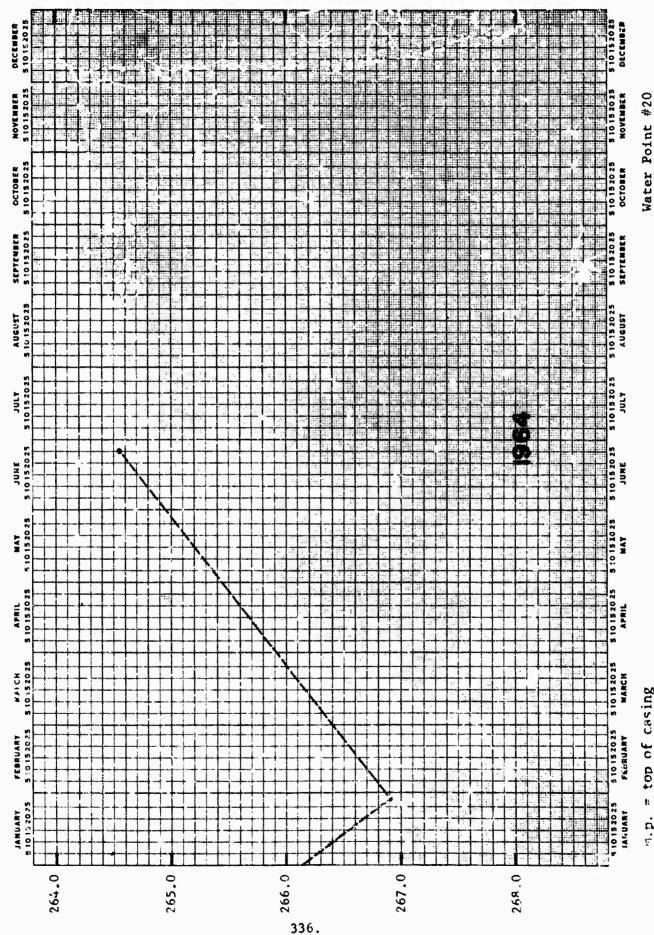
TAX STREET,

333.

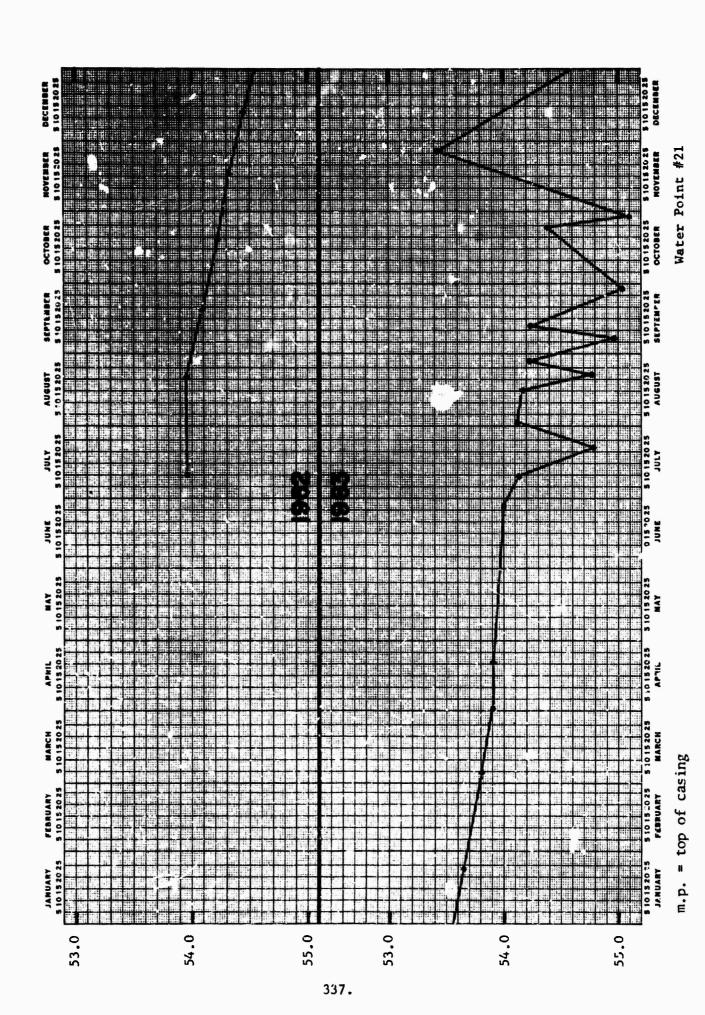


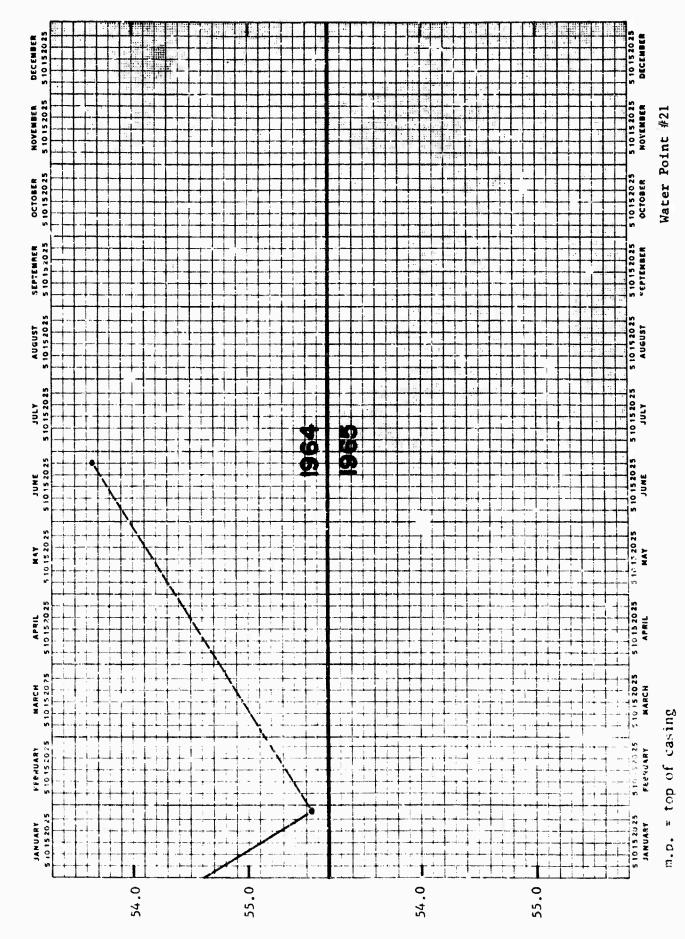
334.





casing top of ŧ: ٠. تا.





338.

30.0

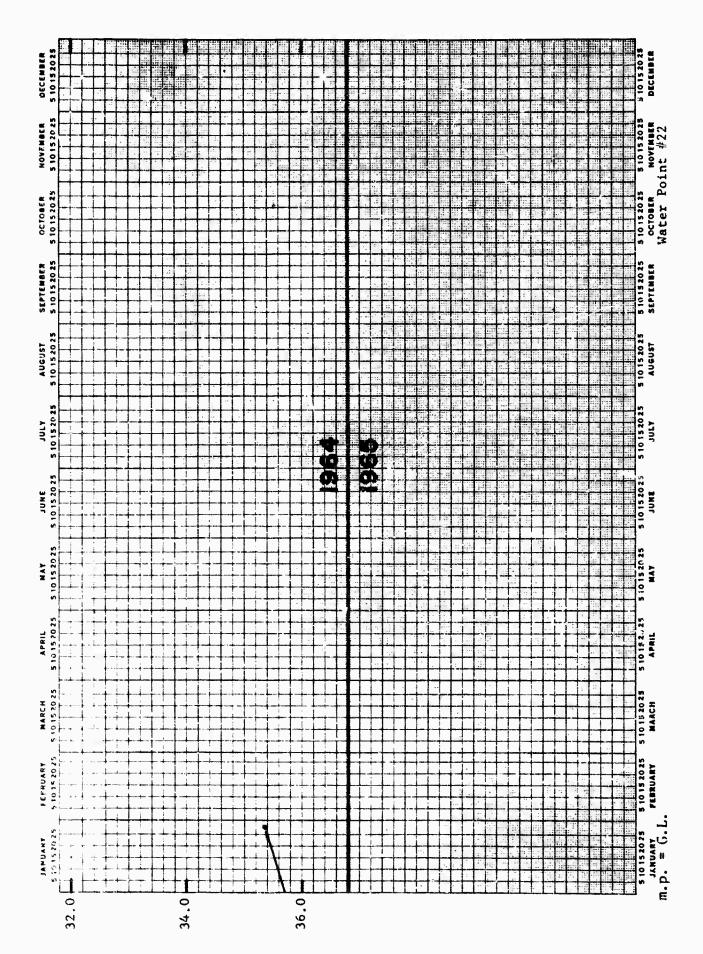
32.0

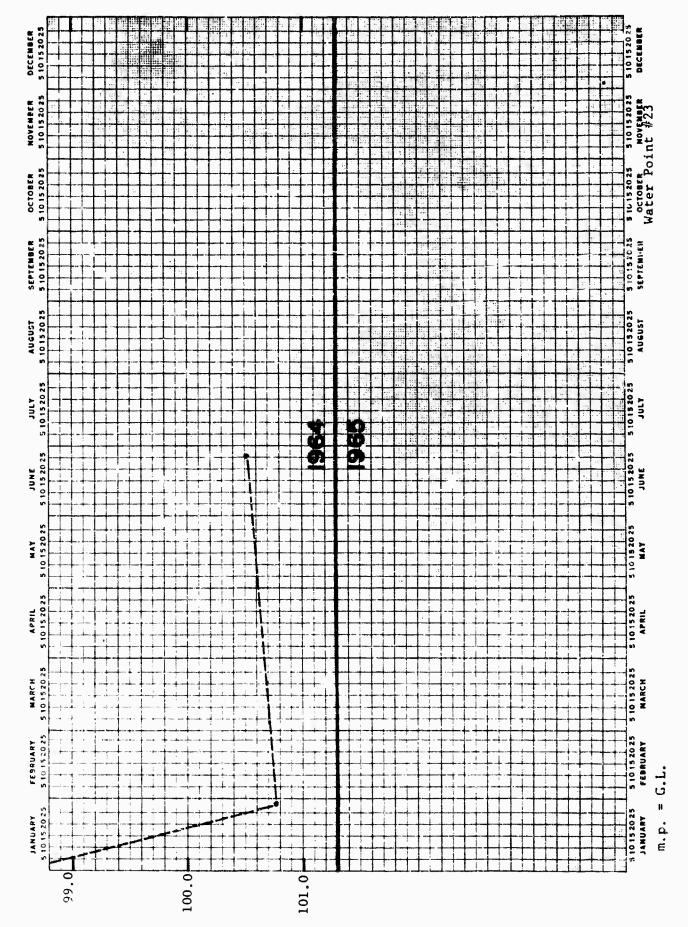
34.0

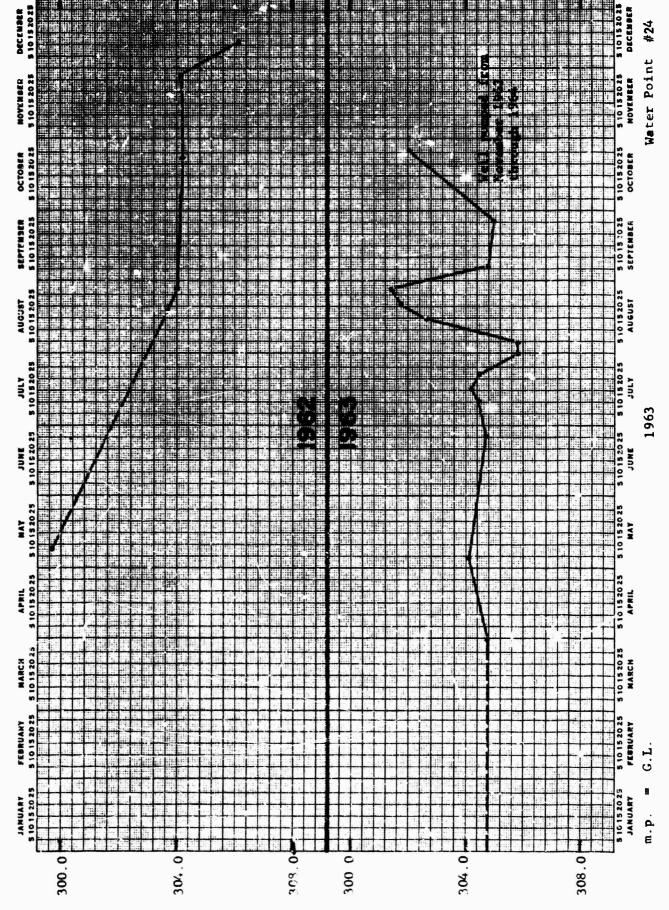
339.

32.6

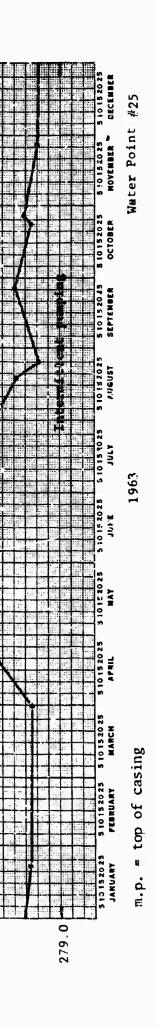
34.0







1962





OCTOBER \$10152025

510152025

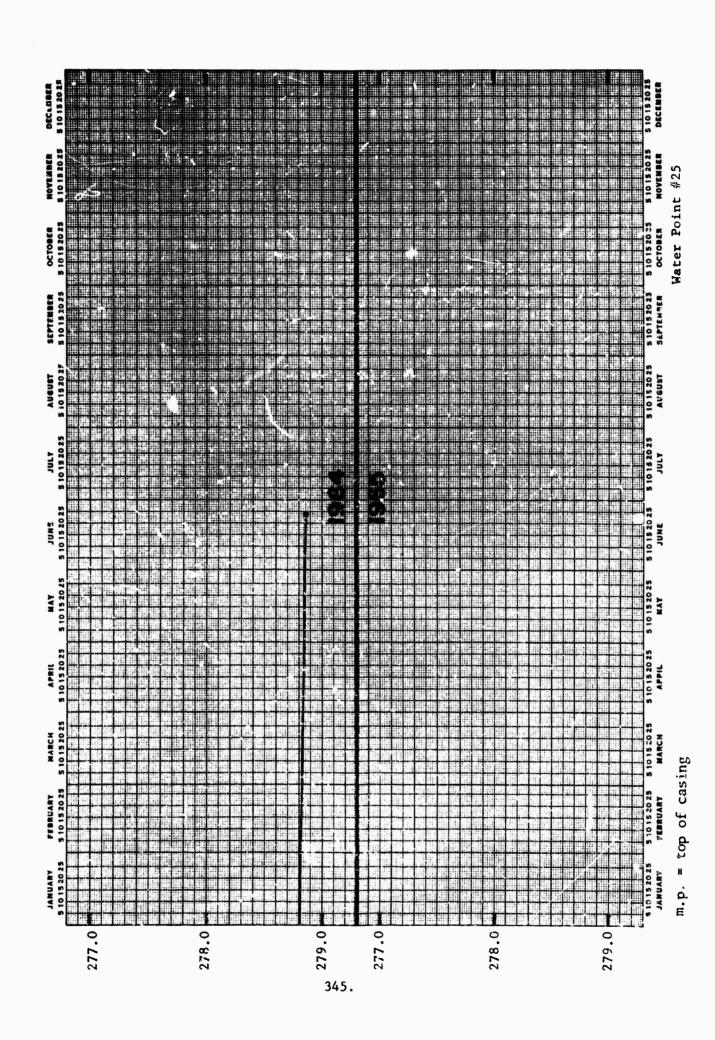
277.0

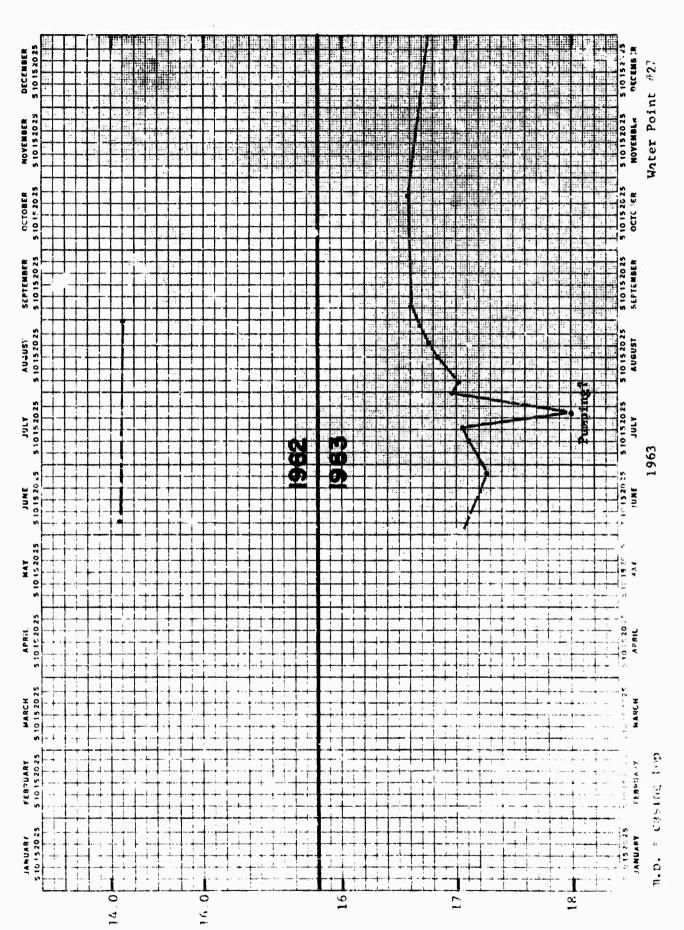
278.0

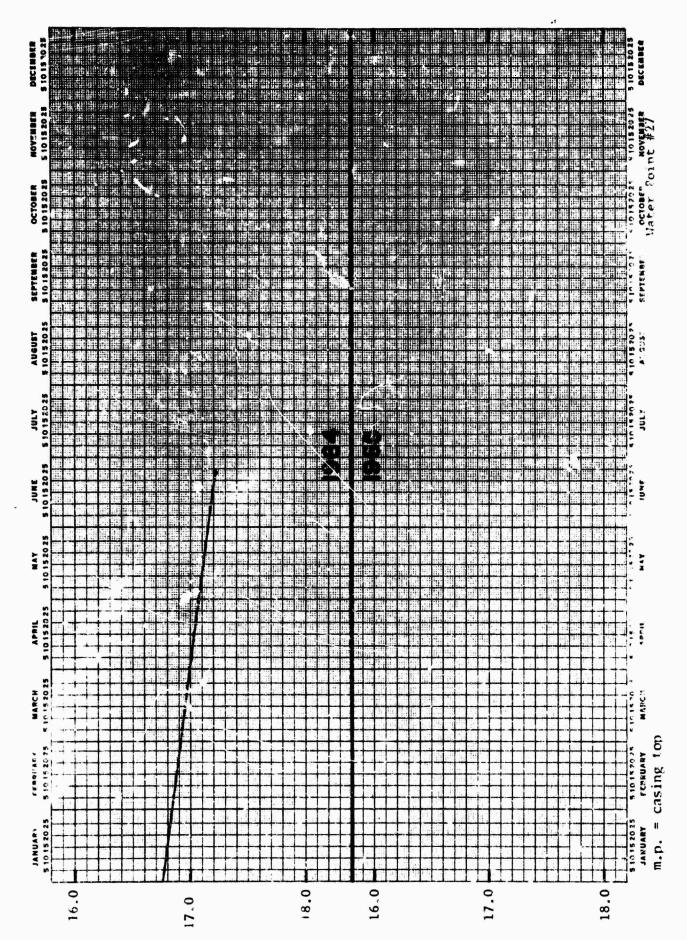
279.0

344.

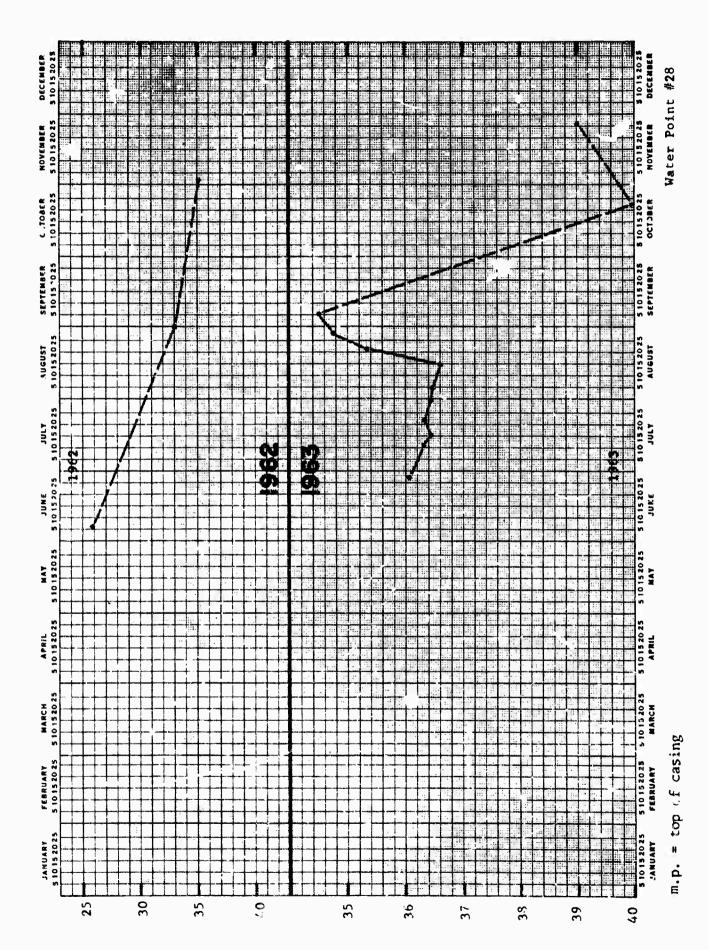
277.0



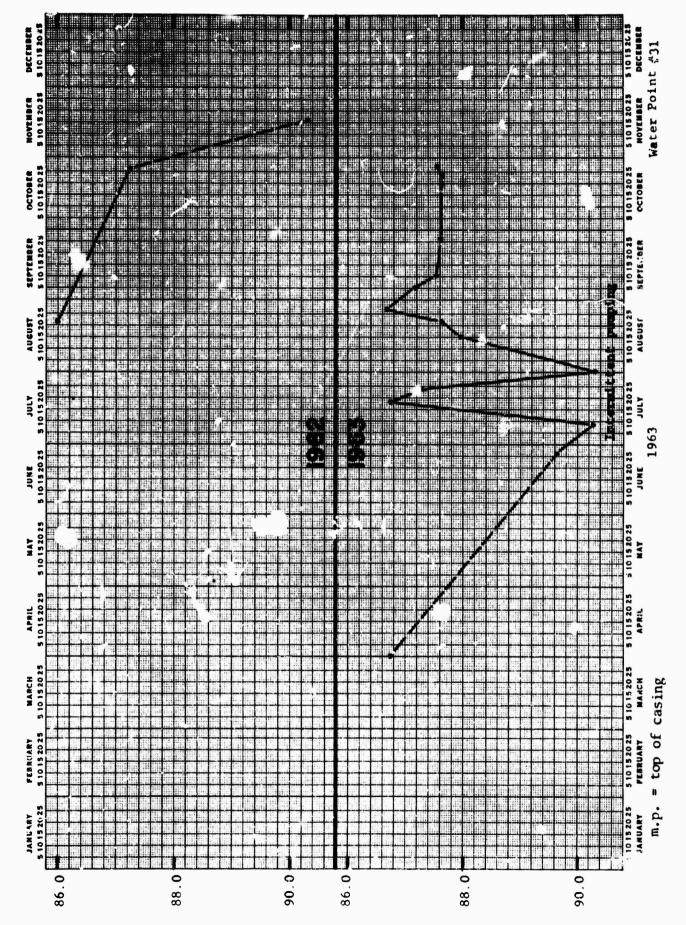




347.

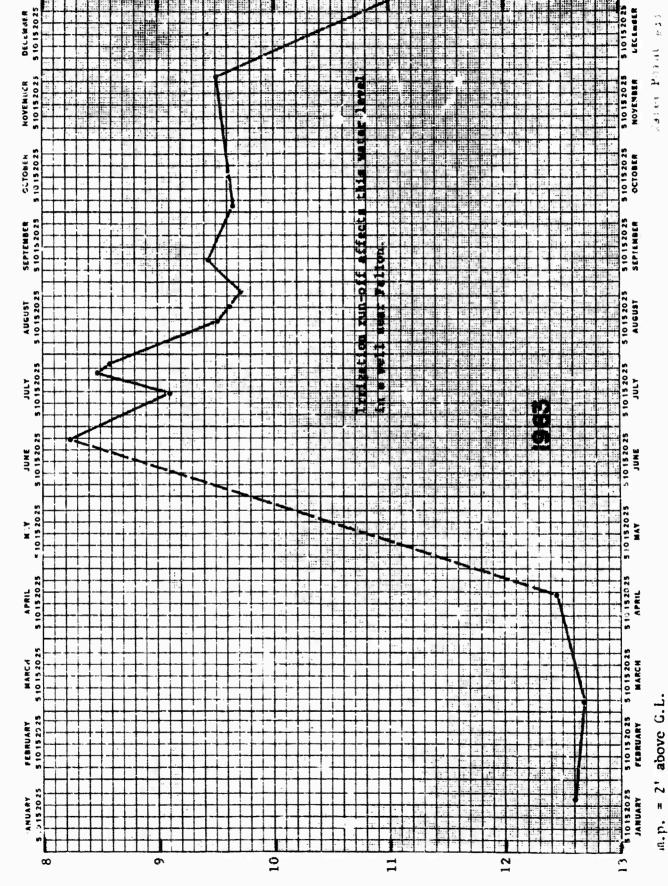


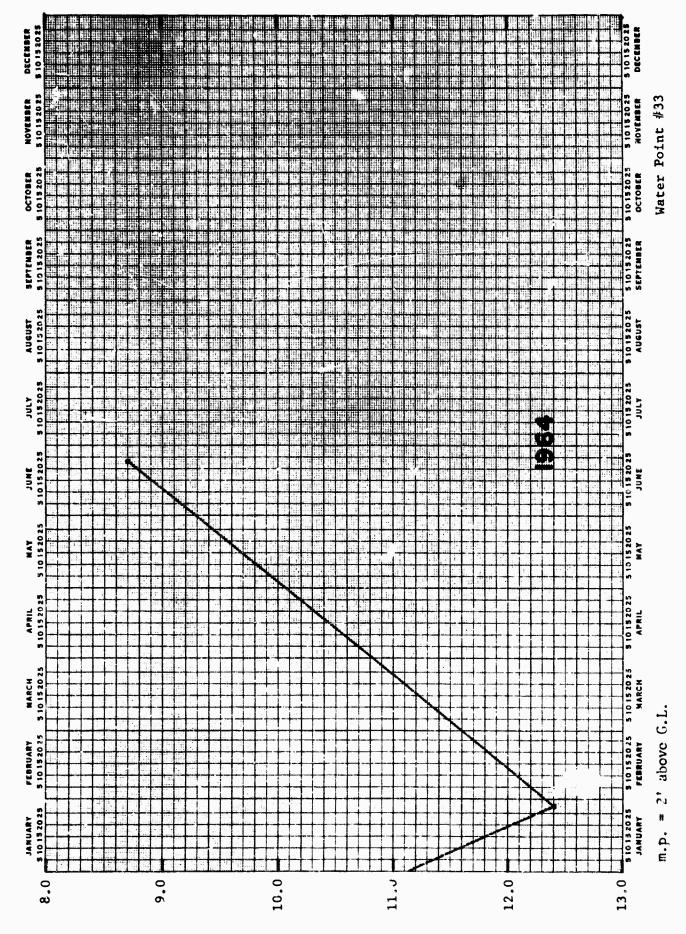
348.



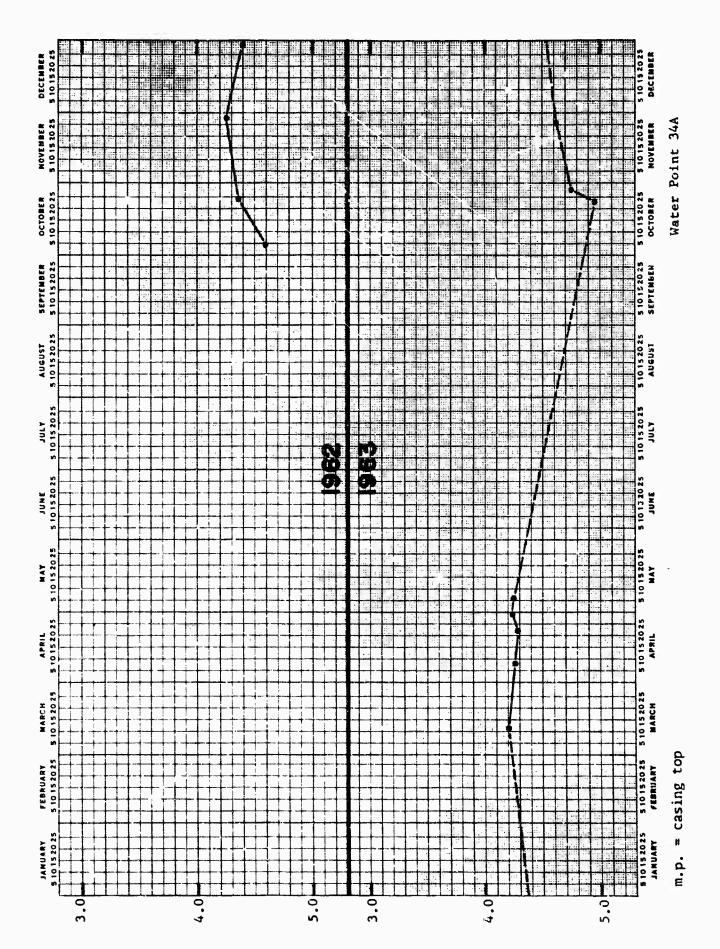
1962







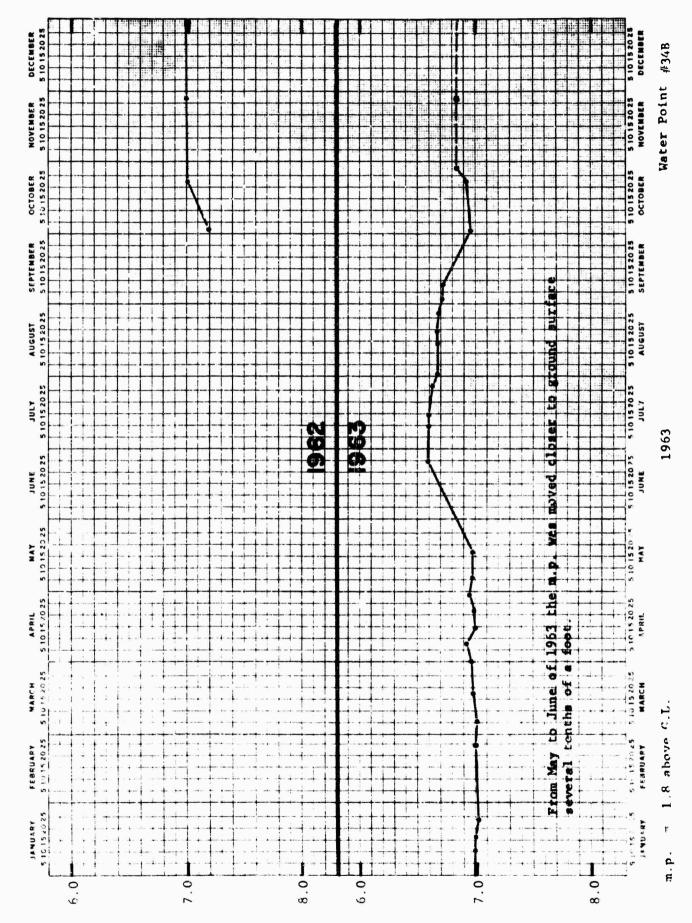
351.



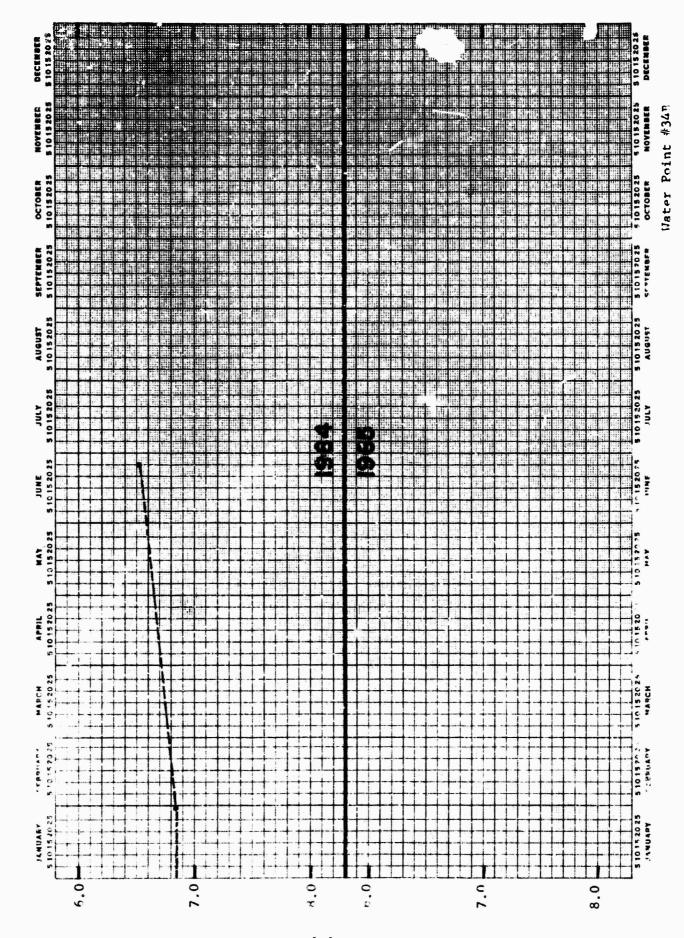
ŧ ;



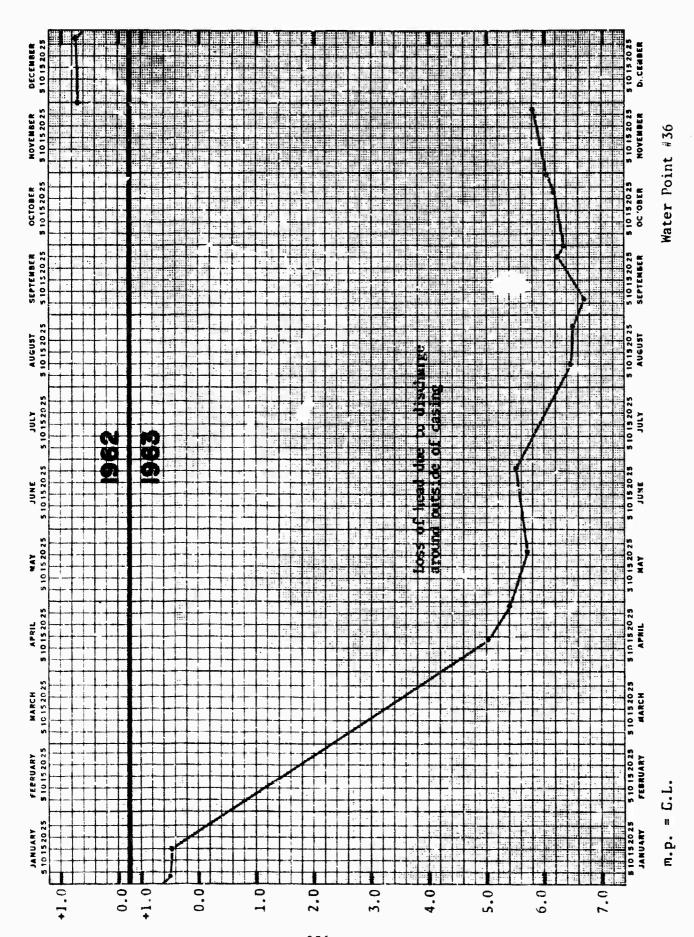
the state of the state of the state of



3.4



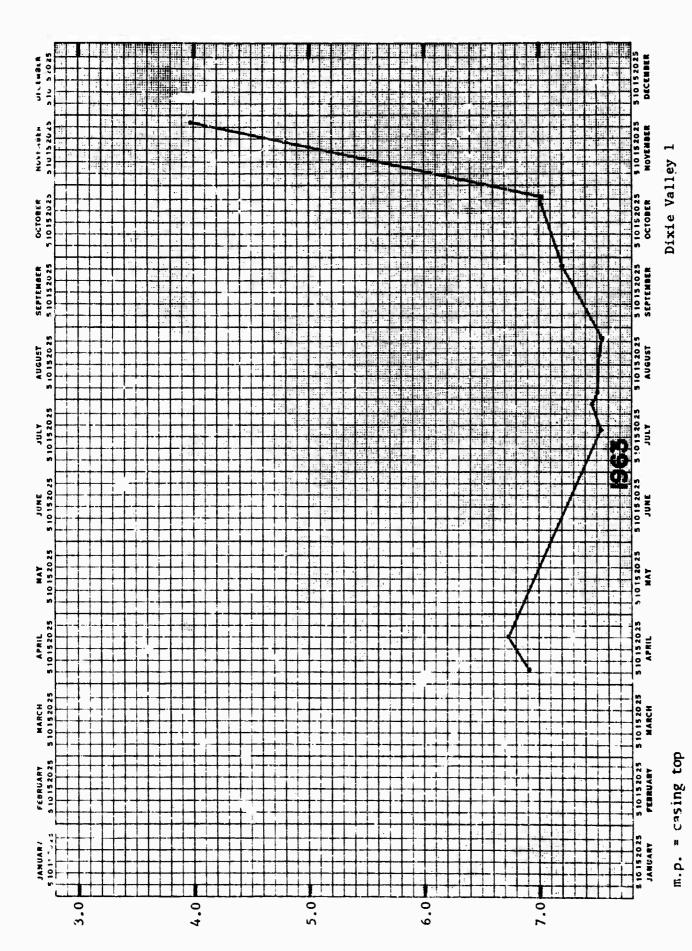
THE RESERVE OF THE PARTY OF



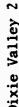
356.

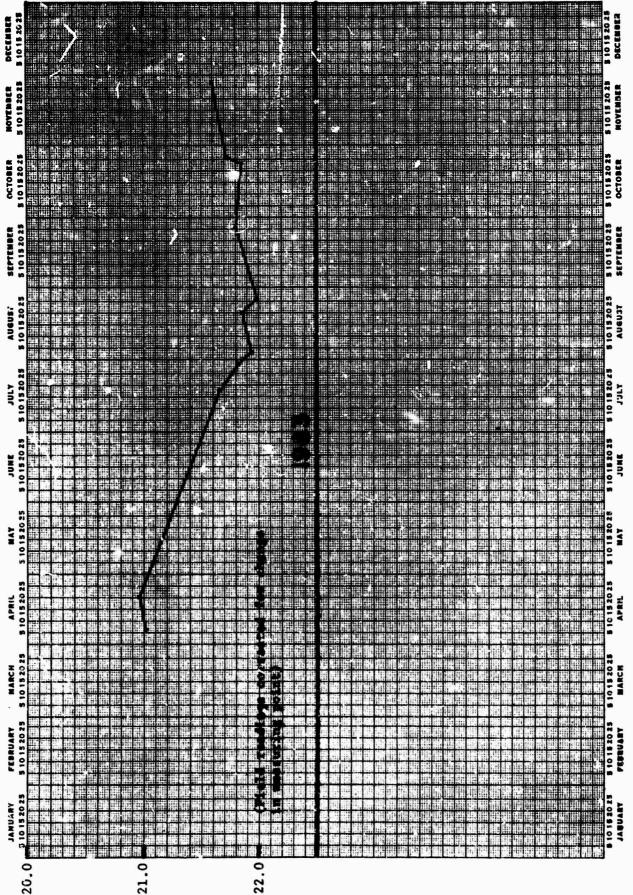
357.

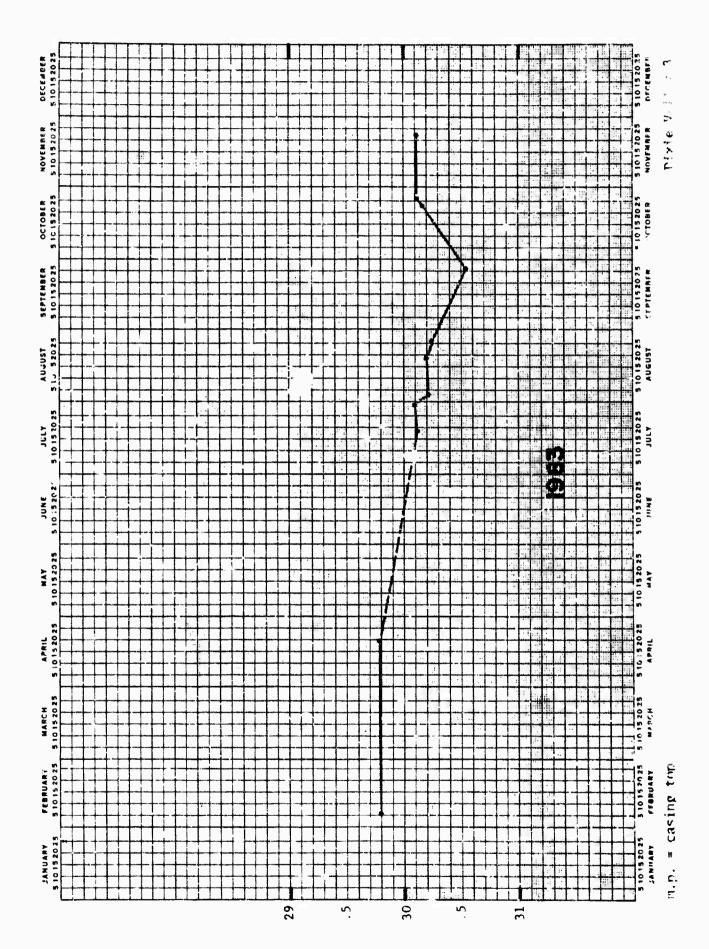
OF THE PERSON NAMED IN



358.



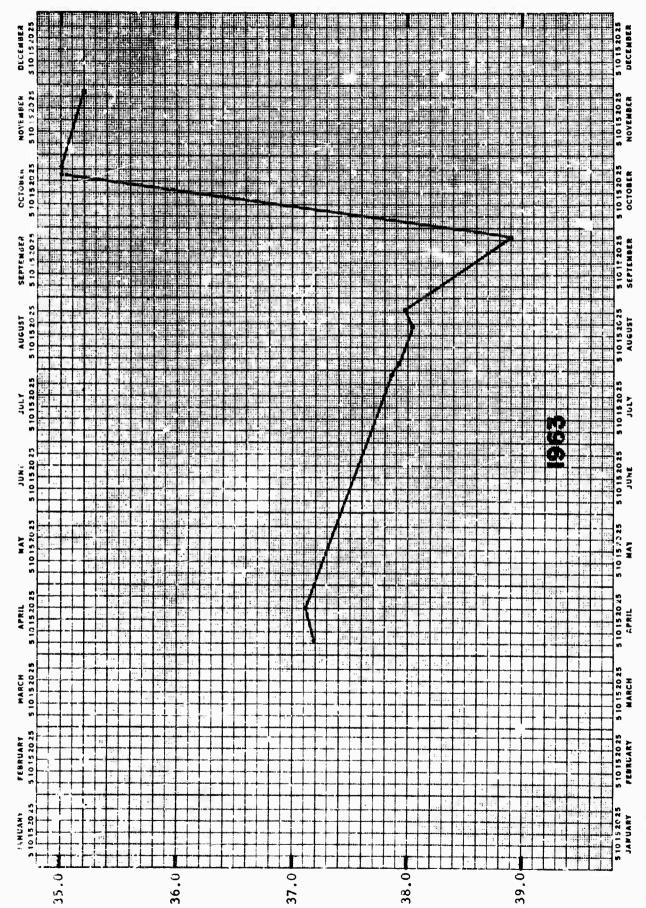




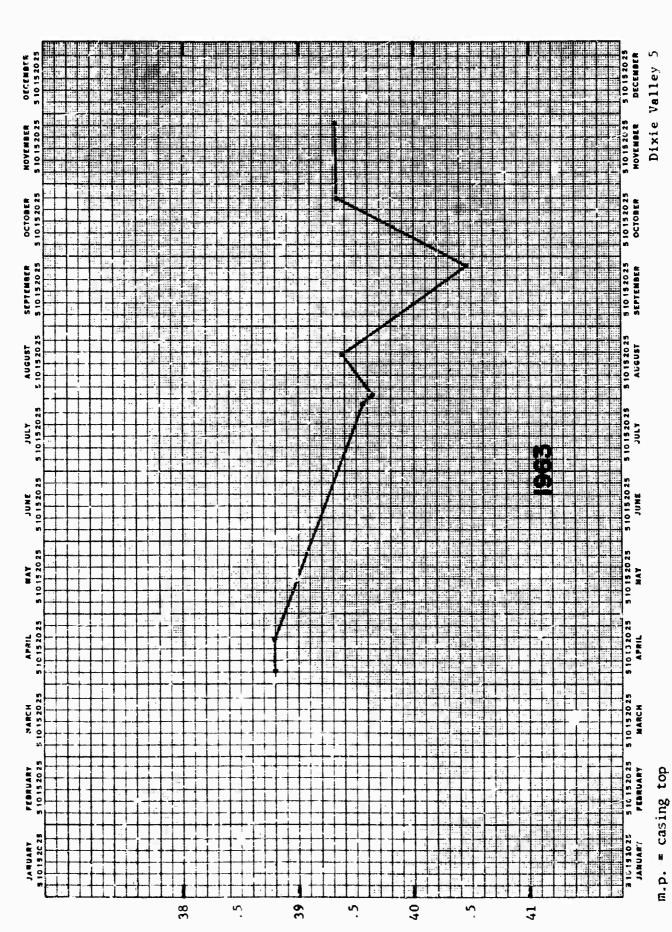
casing top

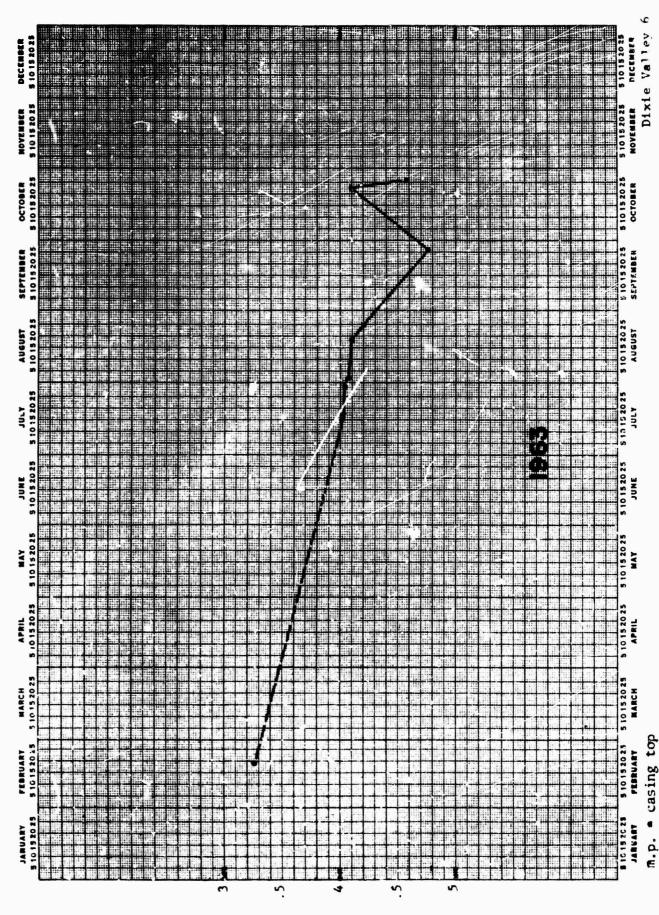
#

m.p.

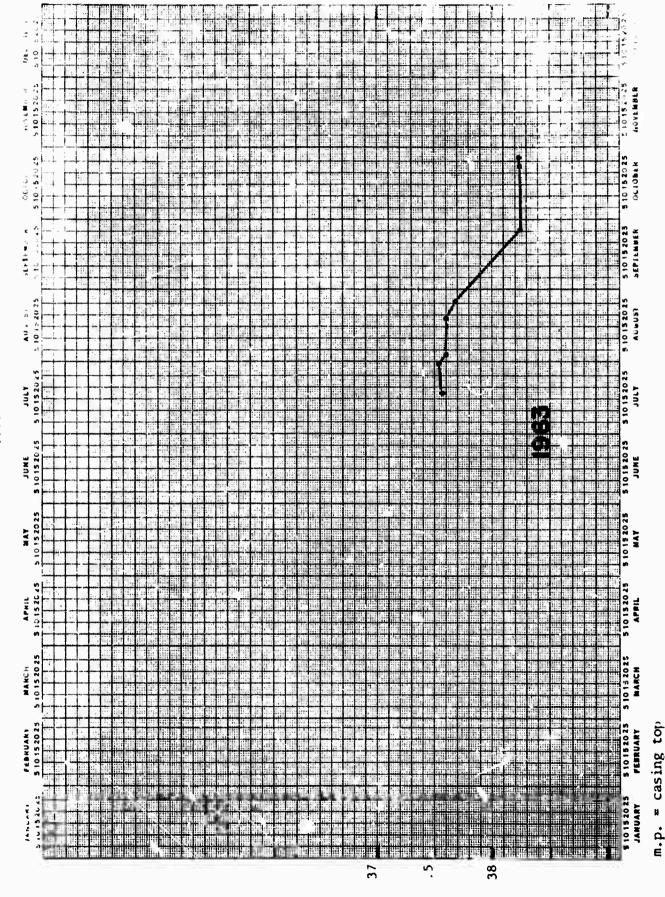












TECHNICAL REPORTS SUB-DISLED FOR ISSUANCE DY AGENELIAS LARITCHEATUNG IN PROJECT SHOAL

AEC REPORTS

Subject or Title Geological, Geophysical and Hydrological Investigations of the Sand Springs Range, Fairview Valley and Fourmile Flat, Churchill County, Nevada	Seismic Measurements at Sandia Stations	Uydrodynamic Yield Measurements	Device Support, Arming, Stemming and Yield Determination	Radiological Safety	Final Timing and Firing Report - Final Photo Report	Subsurface Fracturing From Shoal Nuclear Detonation	Weather and Surface Radiation Prediction	Off-Site Surveillance	Structural Survey of Privere Mining Properties	ت ماهواداً	
rofect No.	5.04	45.3	45.5	45.6	***09						
Report No.	VUP-1002	VUF-1003	VUF-1004	VUF-1005	VUF-1006	*	VUI - JOOR	VUF-1009	VUF. 1015	7775-7 11	
Agency	၁၄	SC	SC	SC	BOAG	USBM. Fr	บรพา	USPHS	USBM	รประเท	· · ·) H'H d

3/

Agency	Report No.	Project No.	Subject or Title
RFB, Inc.	VUF-1013		Analysis of Shoal Data on Ground Motion and Containment
H-NSC	VUF-1014		Shoal Fost-Shot Hydrologic Safety Report
H&N	VUF-1015		Pre-Shot and Post-Shot Structure Survey
HEAN	VVF-1016		Test of Dribble-Type Structures
FAA	VUF-1017		Federal Aviation Agency Airspace Advisory
		DOD REPORTS	
SC	VUF-2001	1.1	Free Field Earth Motions and Spalling Measurements in Granite
SC	VUF-2002	1.2	Surface Motion Measurements Near Surface
** USC&GS	VUF-2300	1.4	Strong Motion Seismic Measurements
IPI	VUF-2600	1.6	In-Situ Stress in Granite
WES	VUF-2700	6.1	Grouting Support
11s **	VUF-2400	1.7	Shock Spectrum Measurements
SRI	VUF-3001	7.5	Investigation of Visual and Photographic On-Site Techniques
SRI	VUF-3002	7.6	Local Seismic Monitoring - Vela CLOUD GAP Program

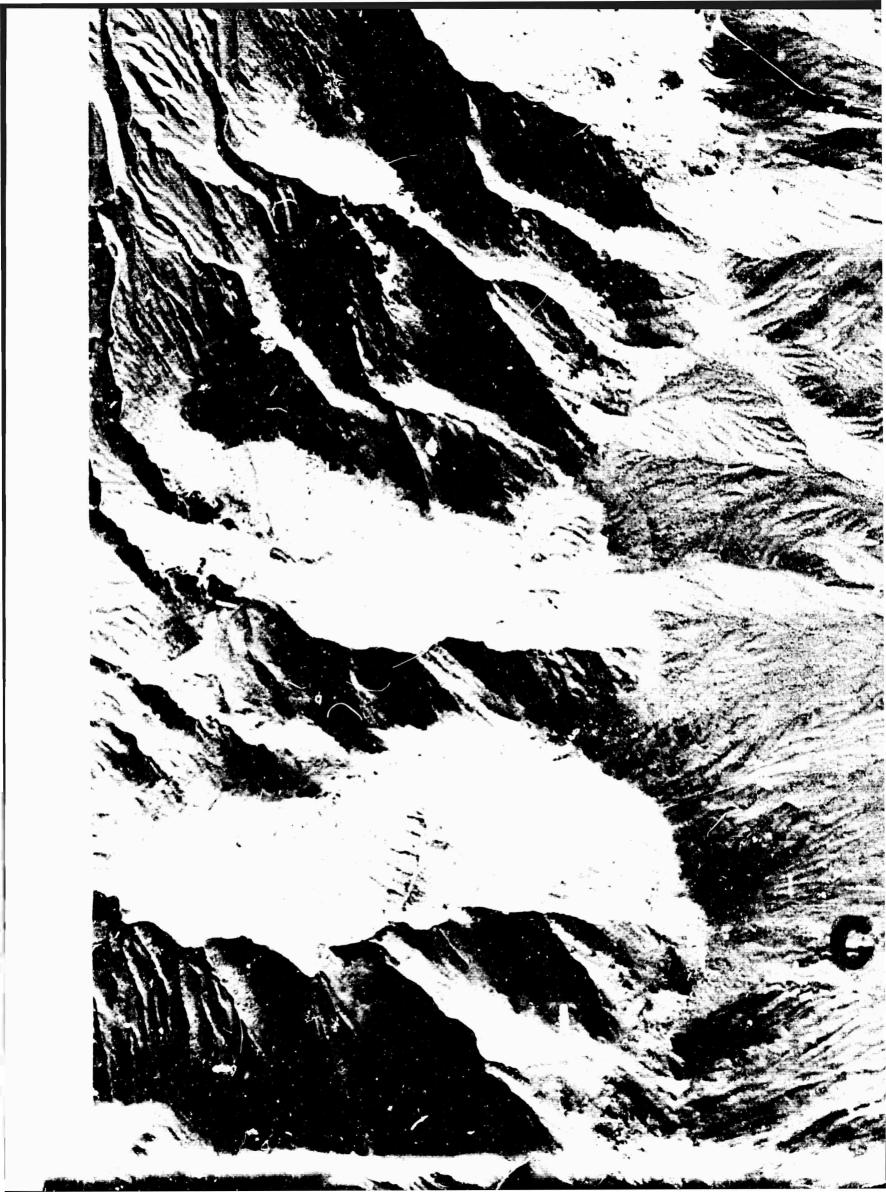
BLANK PAGE











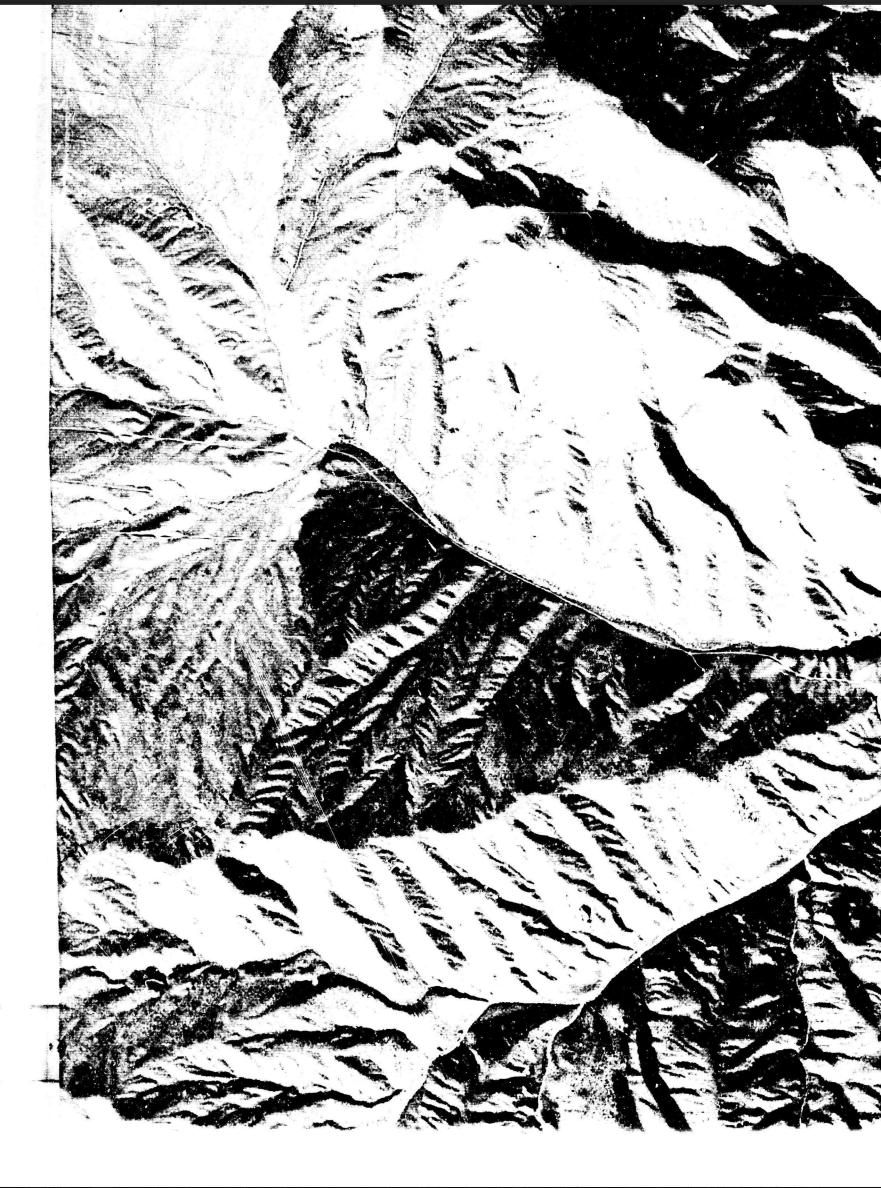


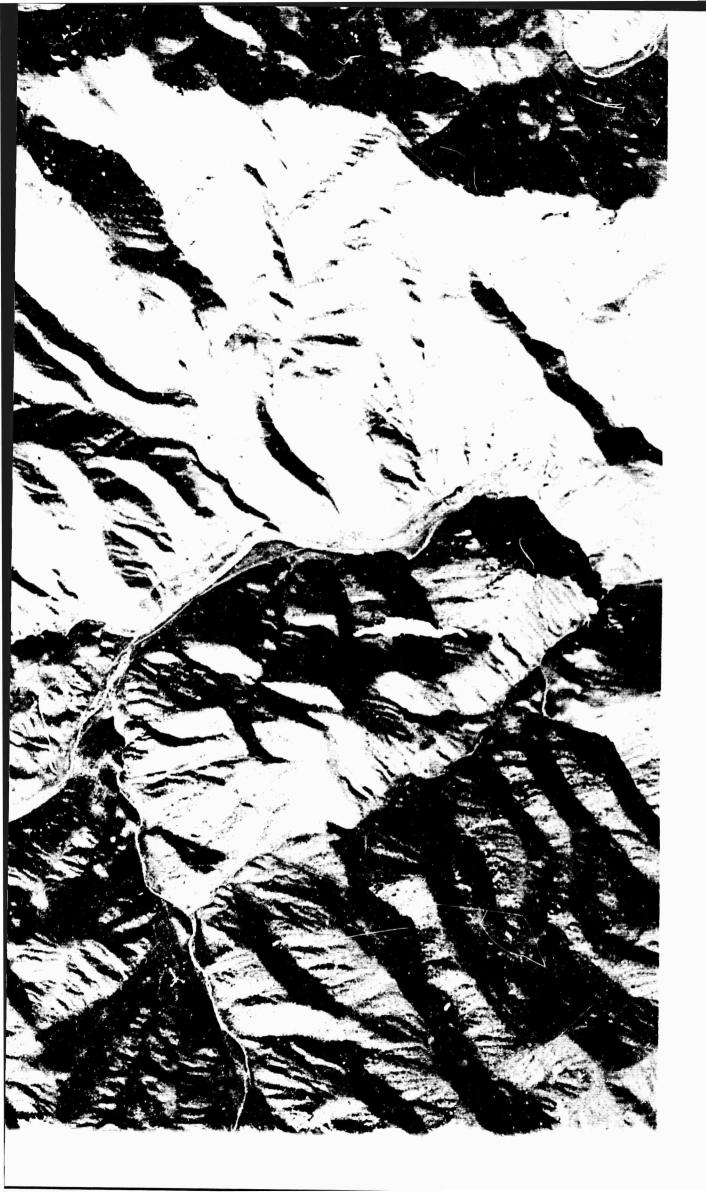


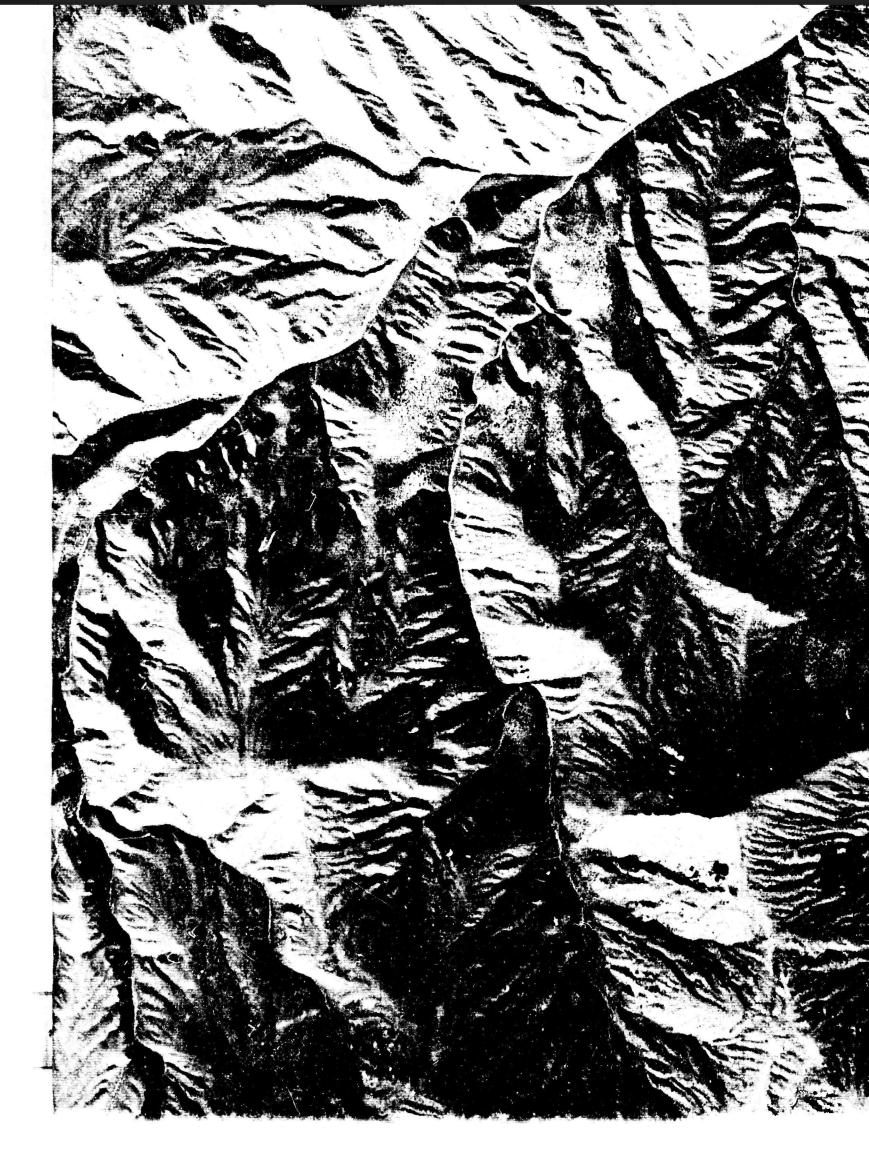
















.....





MACKAY SCH

Î

SCALE: ~ I

ENGINEERING CONTR



NEVADA BUREAU OF MINES

AY SCHOOL OF MINES

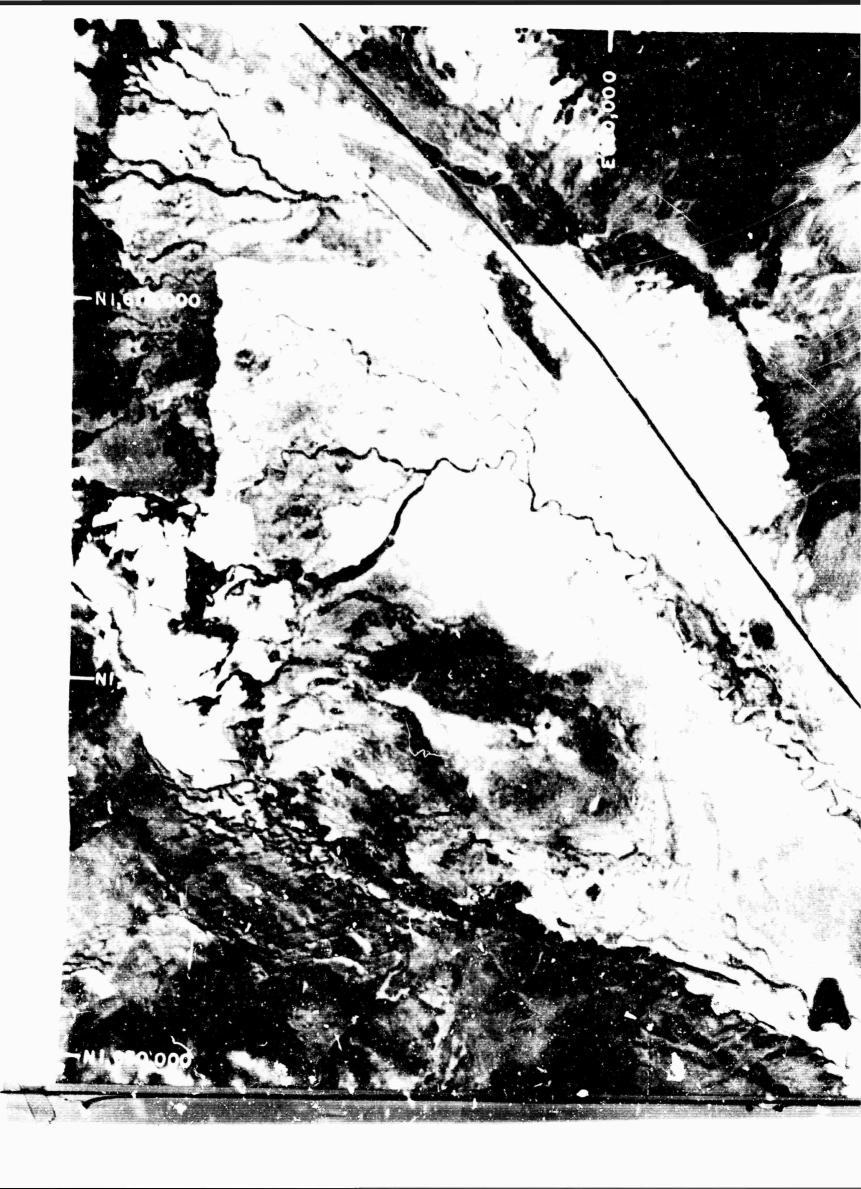
UNIVERSITY OF NEVADA

SEMICONTROLLED PHOTO MOSAIC AREA B (GROUND ZERO AREA)

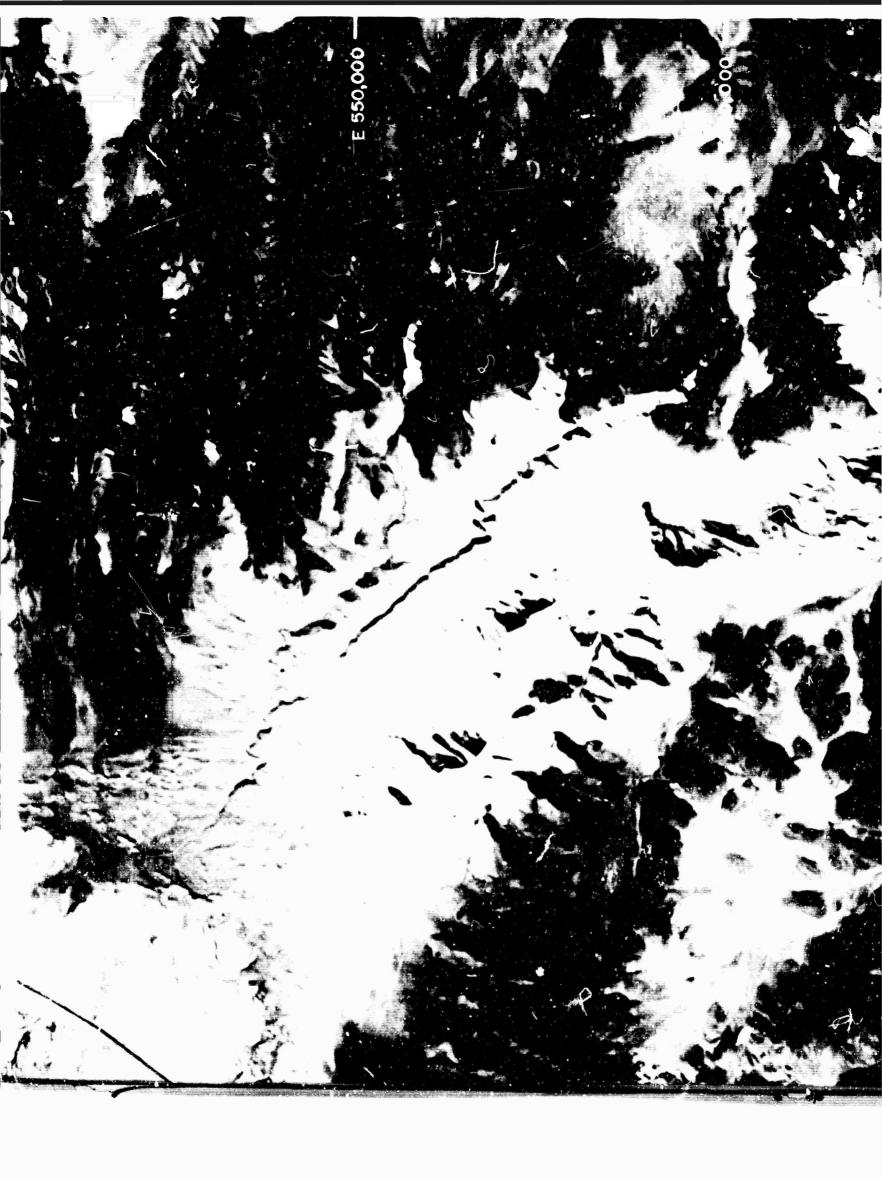
CHURCHILL COUNTY, NEVADA

)	DATE: SEPTEMBER	1962
Sprout Engineers, Inc.		
Mark Hurd Aerial Surveys, Inc		

PLATE 1









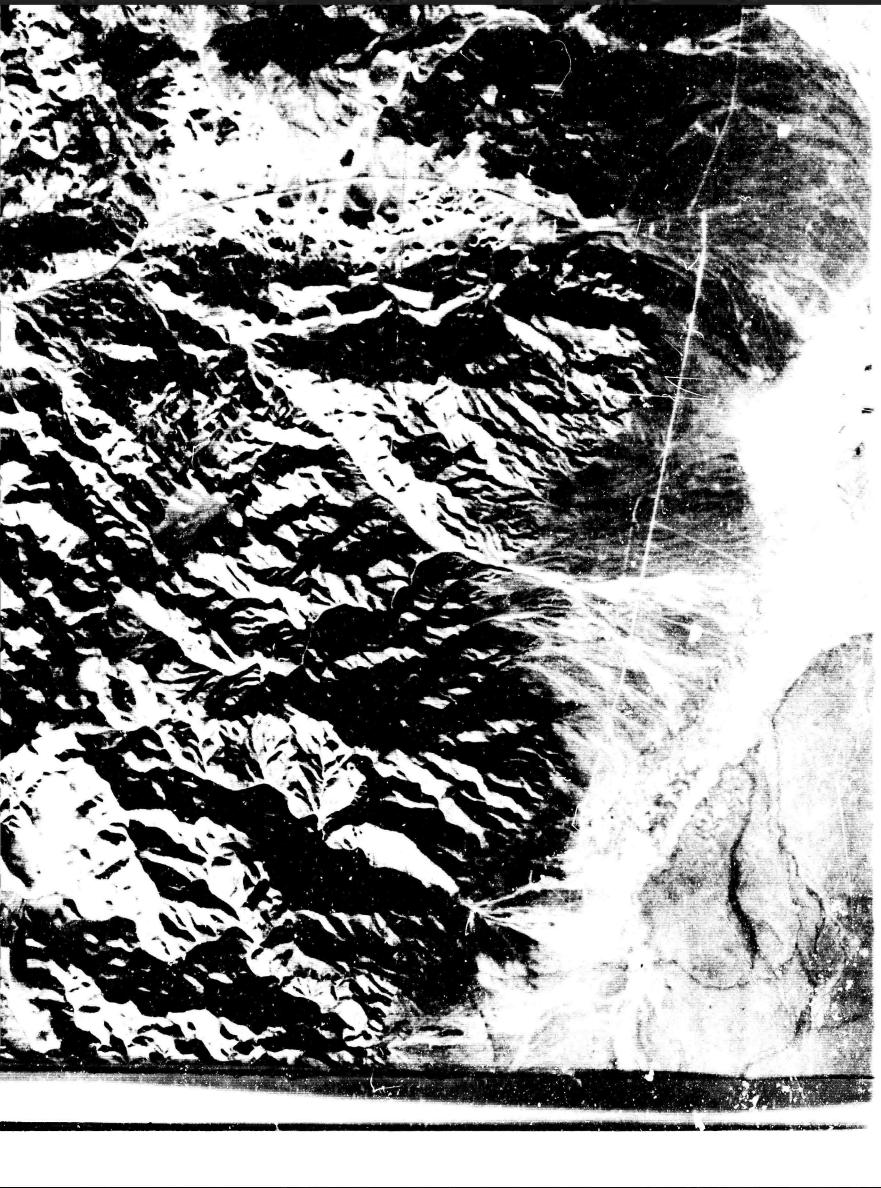






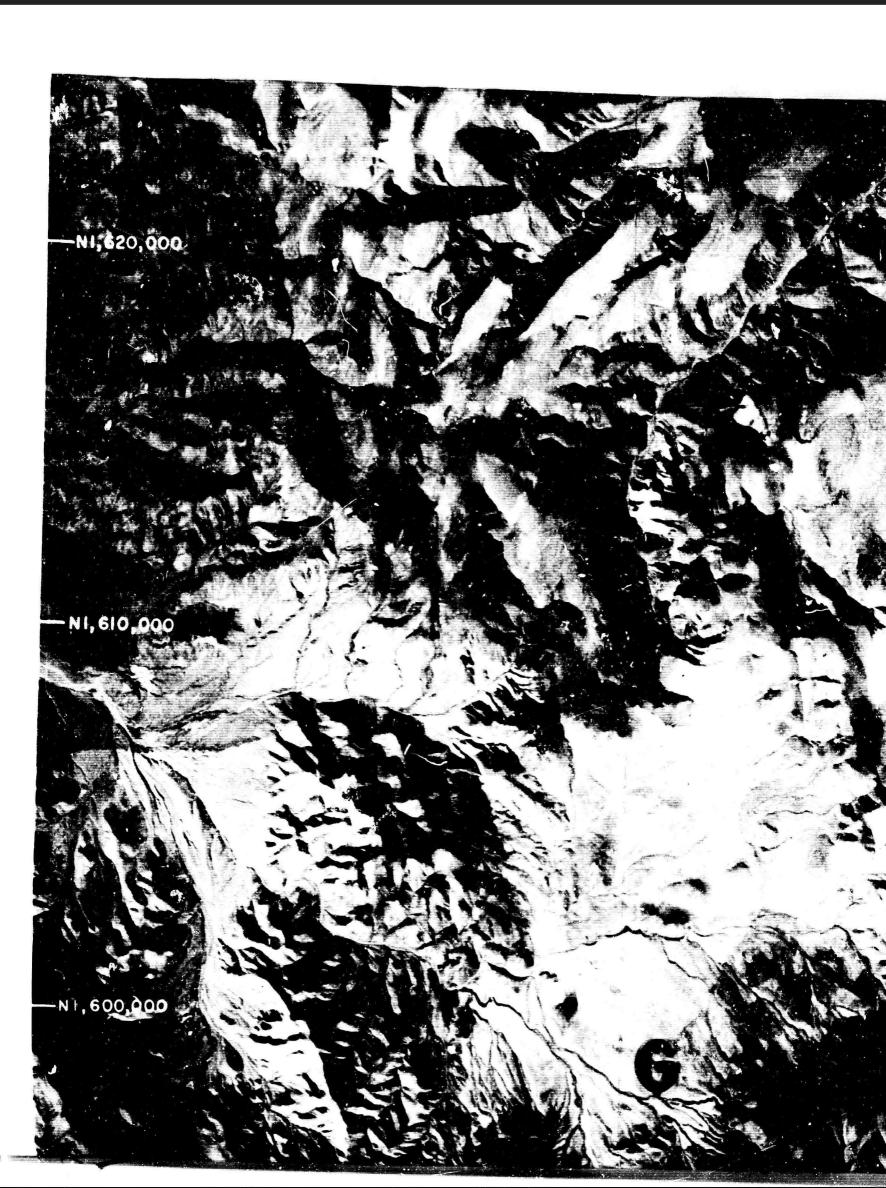




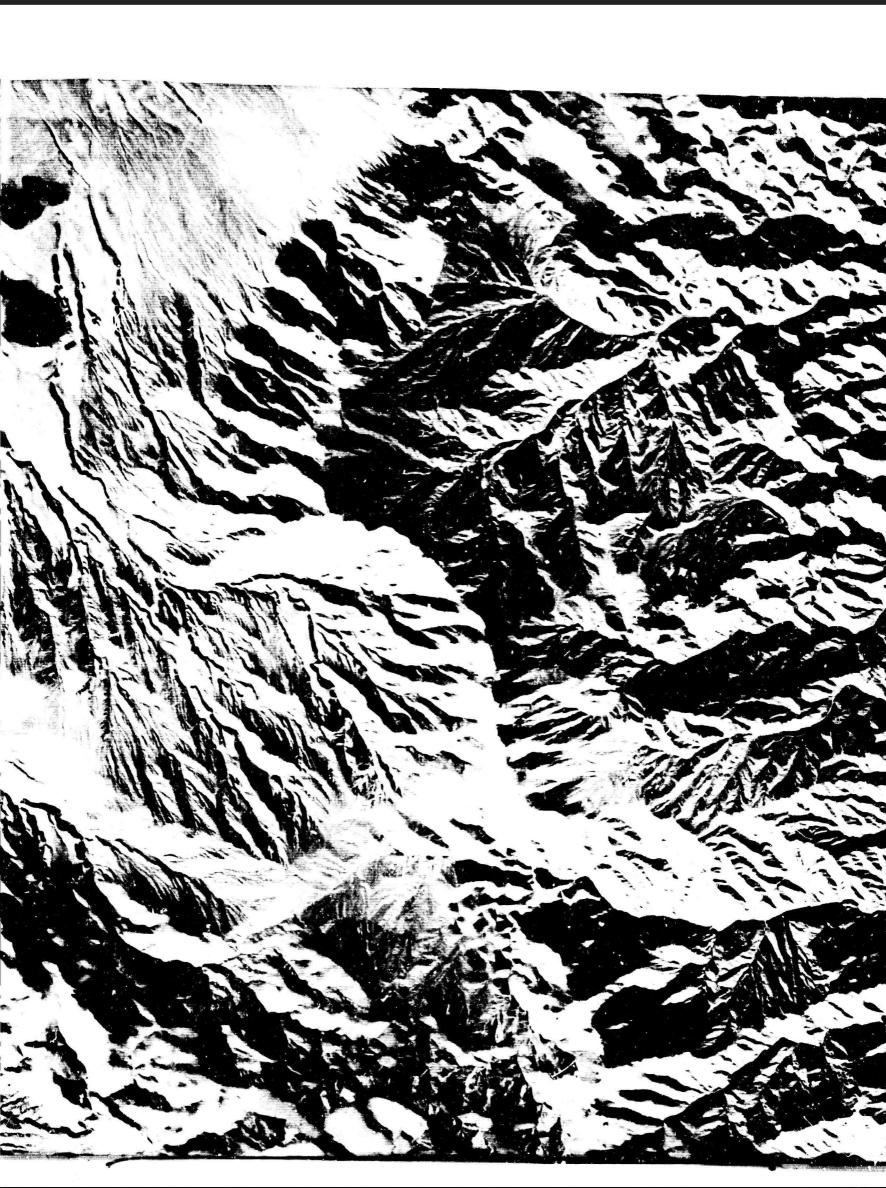






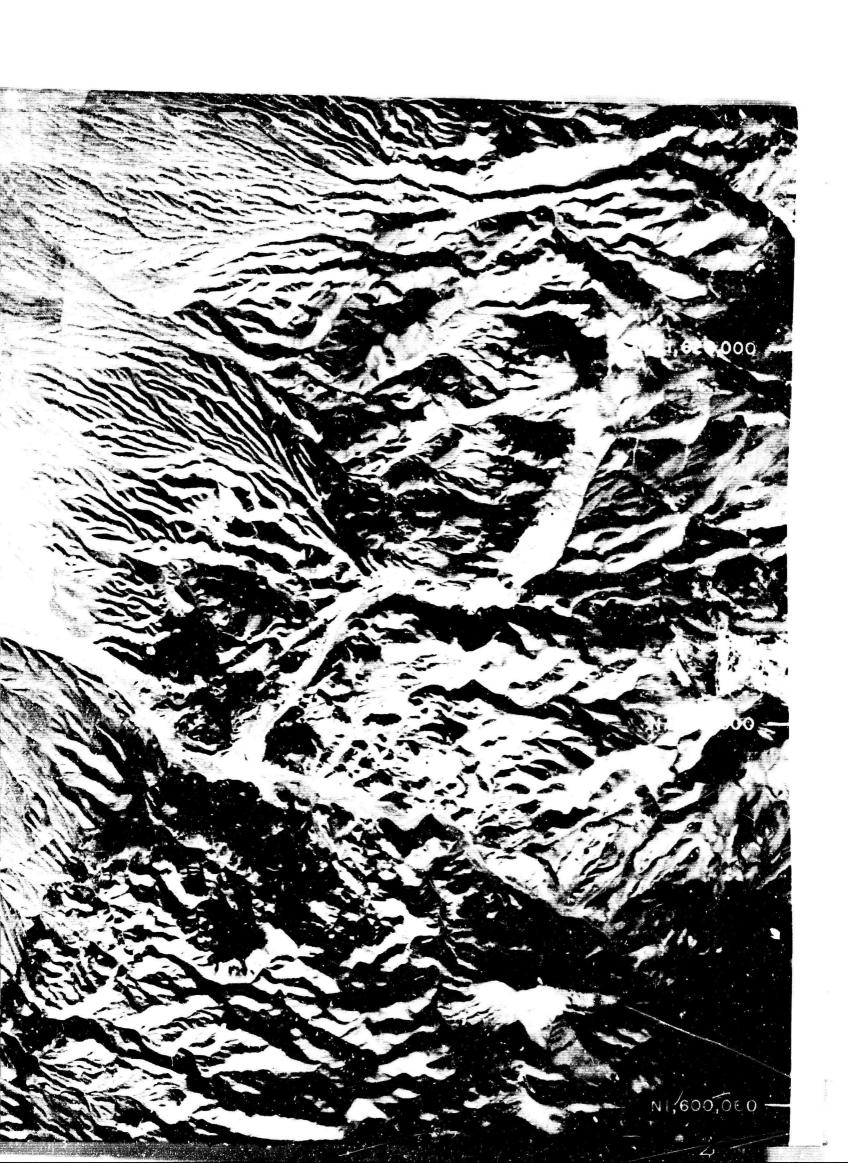












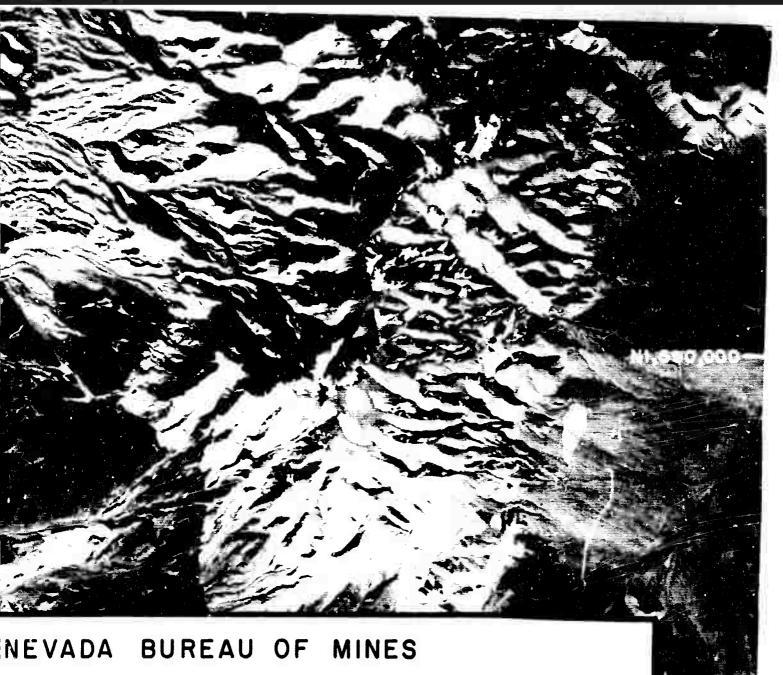












OF MINES

UNIVERSITY OF NEVADA

EMICONTROLLED PHOTO MOSAIC
(SAND SPRINGS RANGE AND ENVIRONS)

CHURCHILL COUNTY, NEVADA

DATE: SEPTEMBER 1962

Sprout Engineers, Inc.

Mark Hurd Aerial Surveys, Inc.

N1,570 0

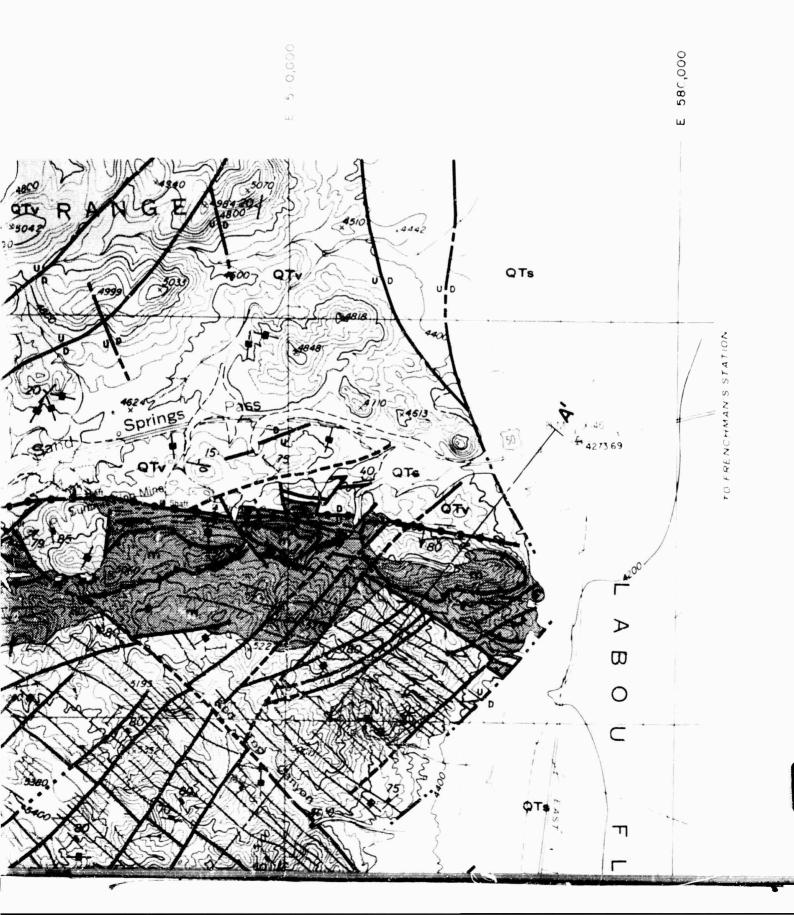
80,000

E. 540,000 N. 1,650,000 -TO FALLON

N. 1,640,000 -

A





B

MESOZOIC

QTs

Sedimentary Rocks

Unconsolidated alluvial and ealian deposits



Volcanic Rocks

Upper basalt flows; a middle rh. litic pyraclastic unit; a lower se of andesitic flows, and bodies vitrophyre



Rhyolite Dikes

White to buff, parphyritic to aphanitic rhyalite



Andesite

Green-black, parphyritic to aphan andesite; and some diabase and diorite



Aplite-Pegmatite Dikes

Cross-hatching indicates areas of abundant dikes



Granitic Body

Biotite granite and harnblende granadiarite



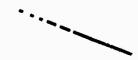
Metamorphic Rocks

Phyllite, schist, slate, recrystallized limestone, and valcanic racks



Contact

Dashed where approximately located datted where canceoled



High-Angle Fault

Dashed where approximately located dotted where cancealed

The second of the second of

QTs

Sedimentary Rocks

Unconsolidated alluvial and ealian deposits



Volcania Rocks

Upper basolt flows, a middle litic pyraclostic unit; a lawe of andesitic flows; and bac vitraphyre



Rhyolite Dikes

White to buff, porphyritic to aphanitic rhyolite



Andesite Dikes

Green-black, parphyritic to ap andesite, and some diabash diarite



Aplite-Pegmatite Dikes

Crass-hatching indicates areas of abundant dikes



Granitic Body

Biotite granite and hornblende granadiorite

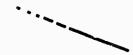


Metamorphic Rocks

Phyllite, schist, slate, recrystollized limestone, and valcanic racks



Dashed where approximately datted where concealed



High-Angle Fault

Dashed where approximately is doited where concealed

MESOZOIC

ldle rhyoower sequence bodies of

S

aphanitic os^ and



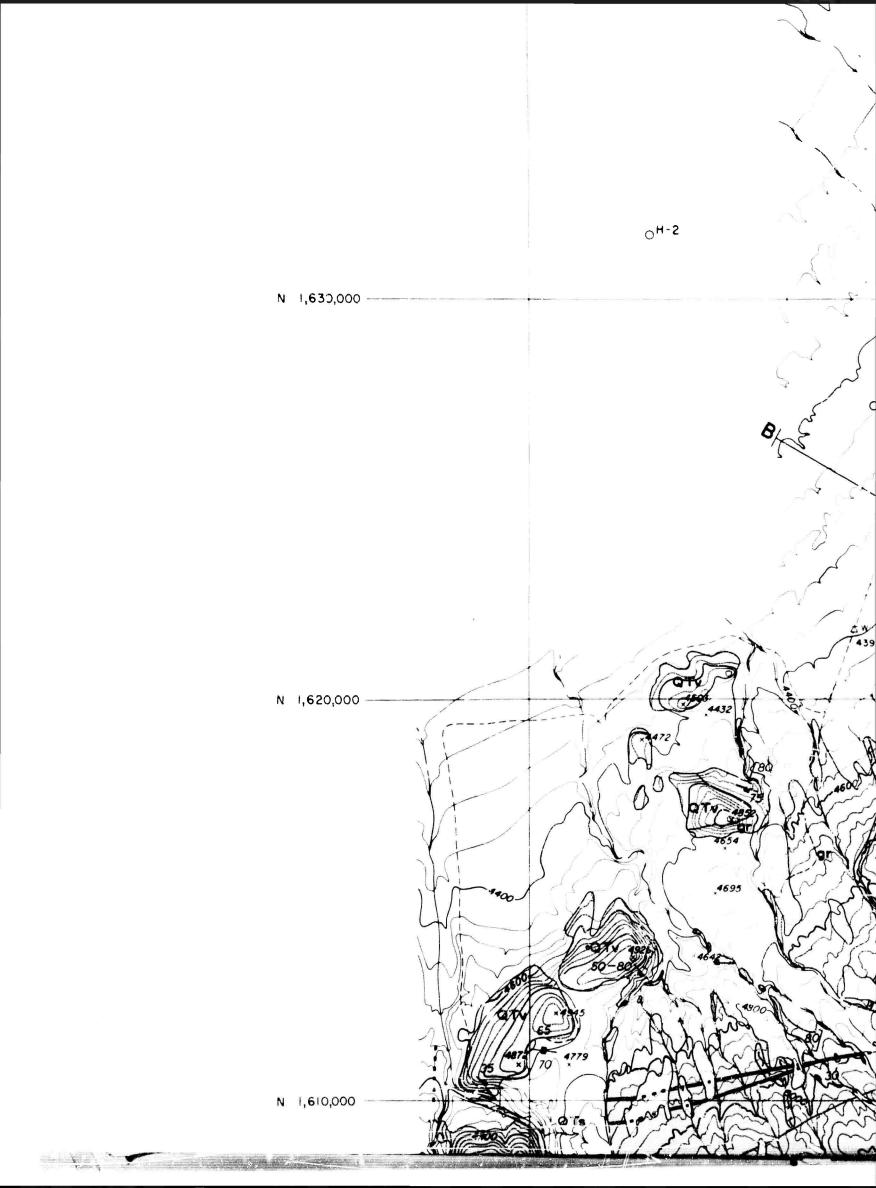
Intrusive Breccia

Inclusions of andesite and other rock types in on optitic groundmass

/ coted,

l†

r located,





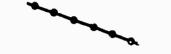




Fault or Shear Zone



Thrust Fault Sawtecth an upper plate



Summit King Vein System



Strike and Dip of Beds



Strike and Dip of Follation

30, 90,

Strike and Dip of Fracture Cleavage

30 90

Strike and Dip of Joints

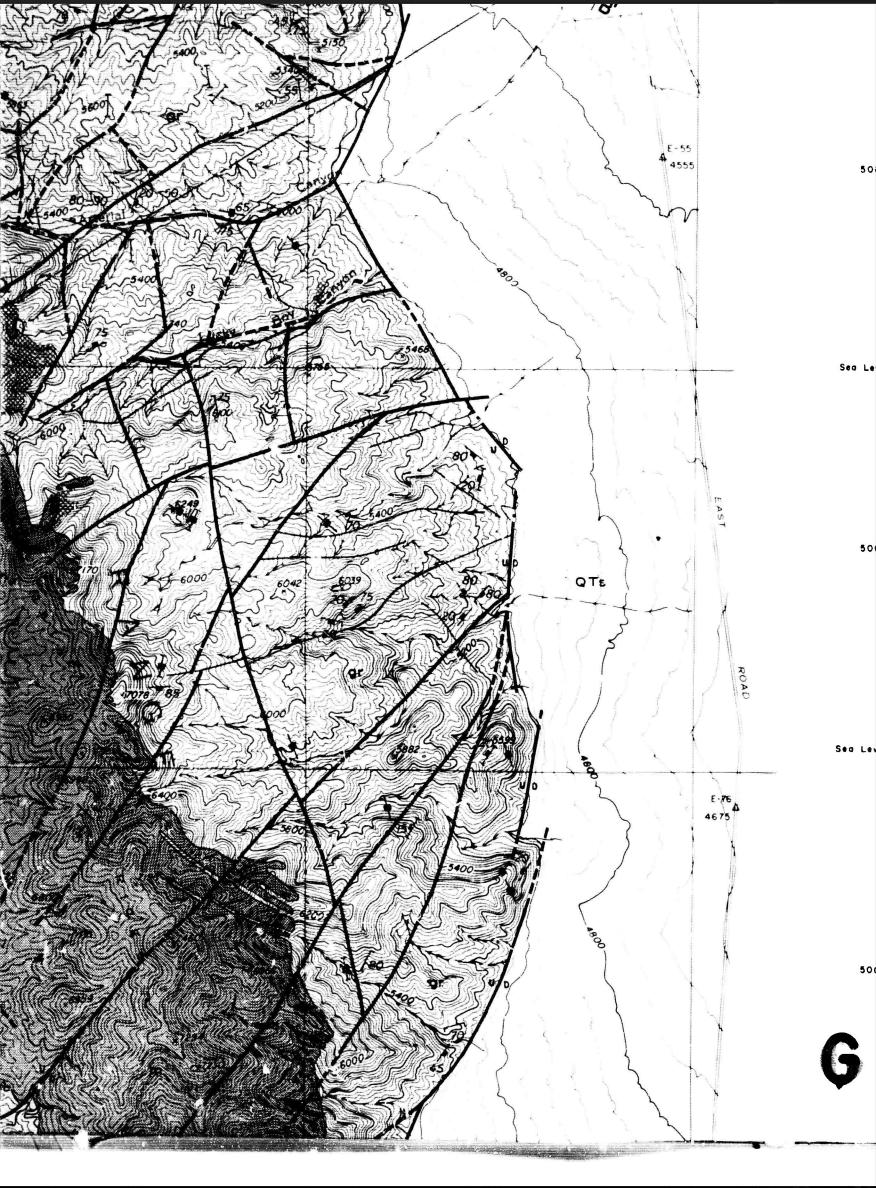
Diamond Drill Hole

0

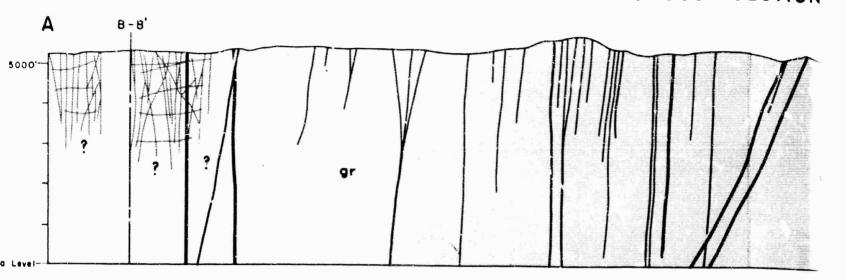
Hydrolegic Drill Hole

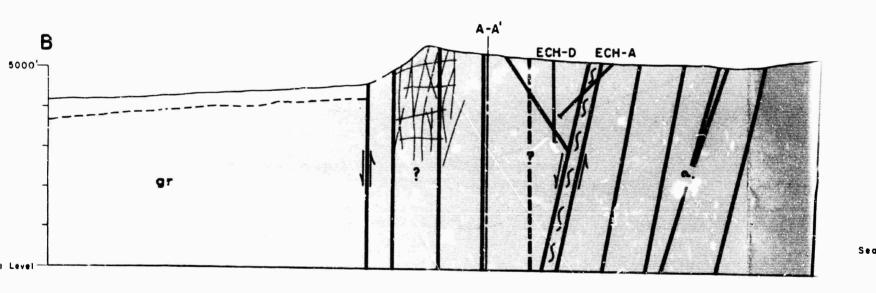


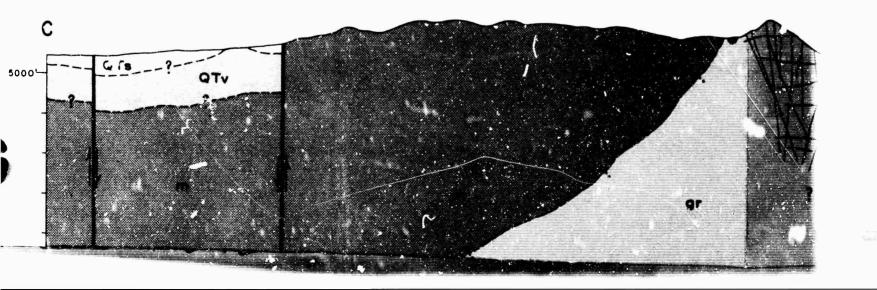




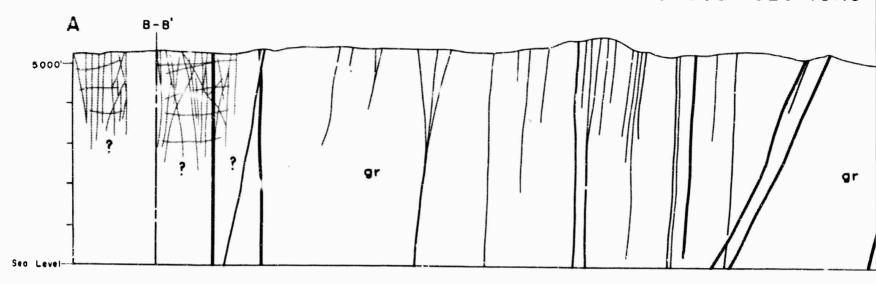
CROSS SECTION

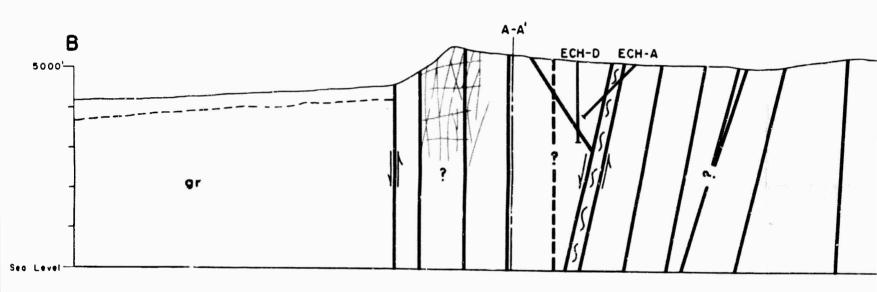


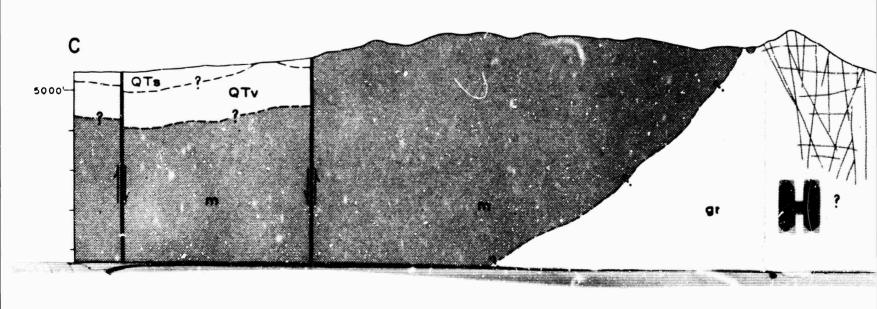


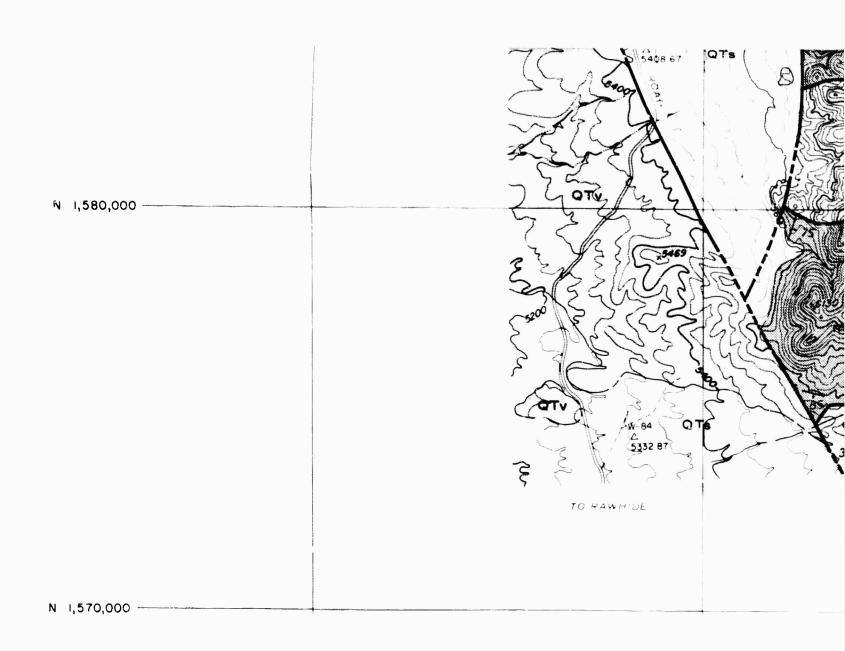


CROSS SECTIONS

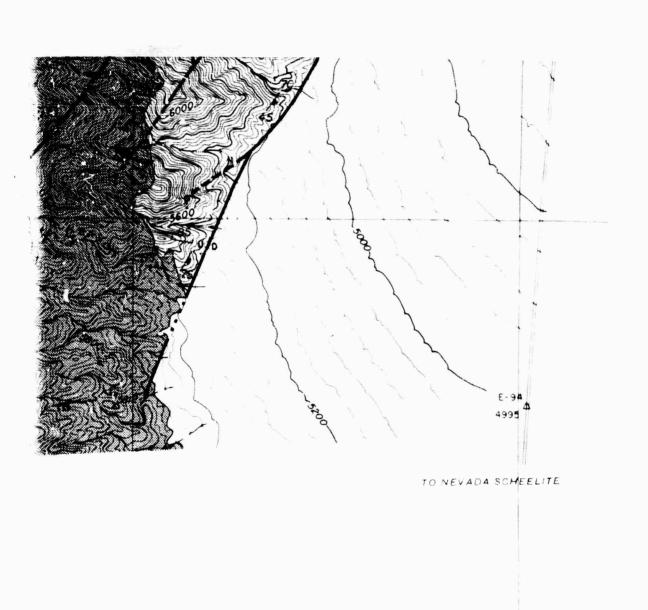


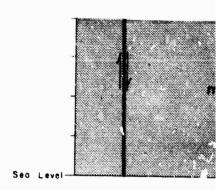


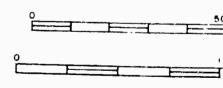


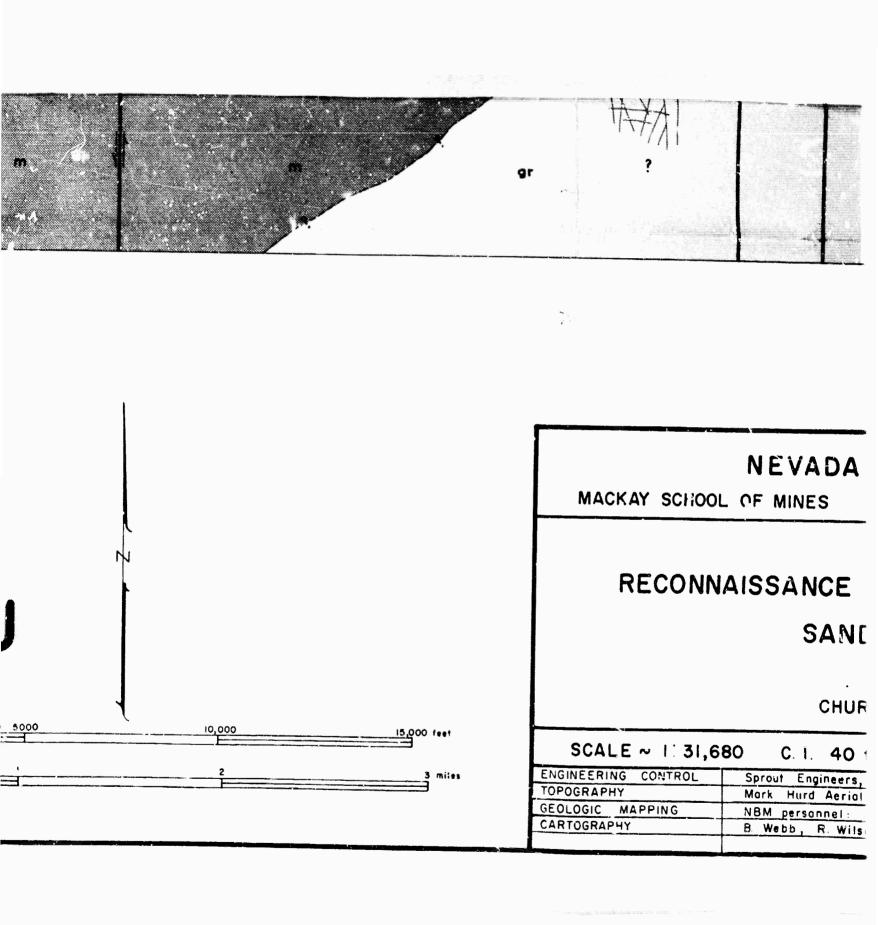


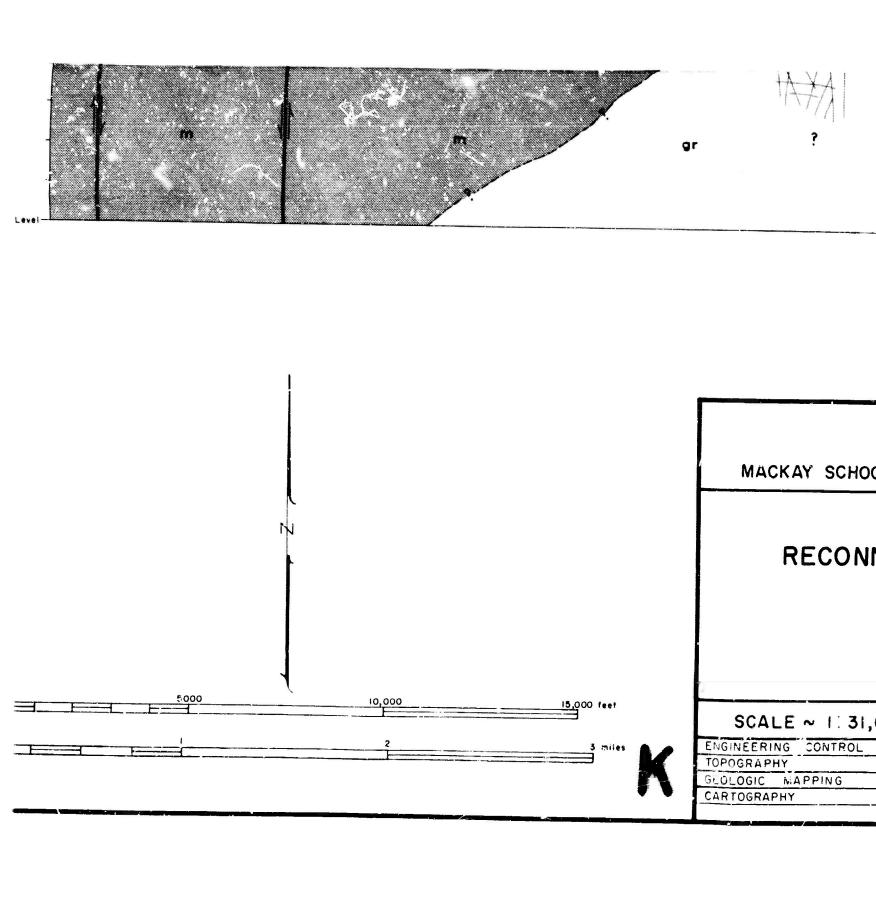


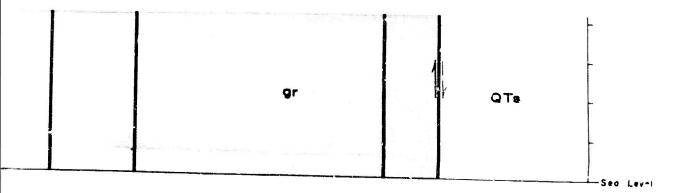












NEVADA BUREAU OF MINES

HOOL OF MINES

UNIVERSITY OF NEVADA

NNAISSANCE GEOLOGIC MAP AND SECTIONS SAND SPRINGS RANGE

CHURCHILL COUNTY, NEVADA

DATE: SEPTEMBER 1962

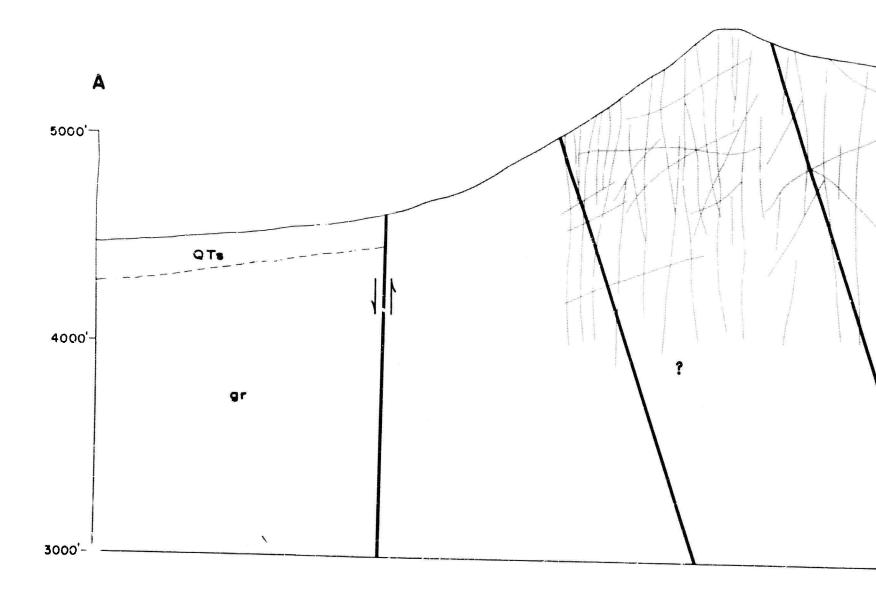
Spraut Engineers, Inc.

Mark Hurd Aerial Surveys, Inc.

NBM personnel: L. Beal, S. Jerome, I. Lutsey, R. Olson, J. Schilling

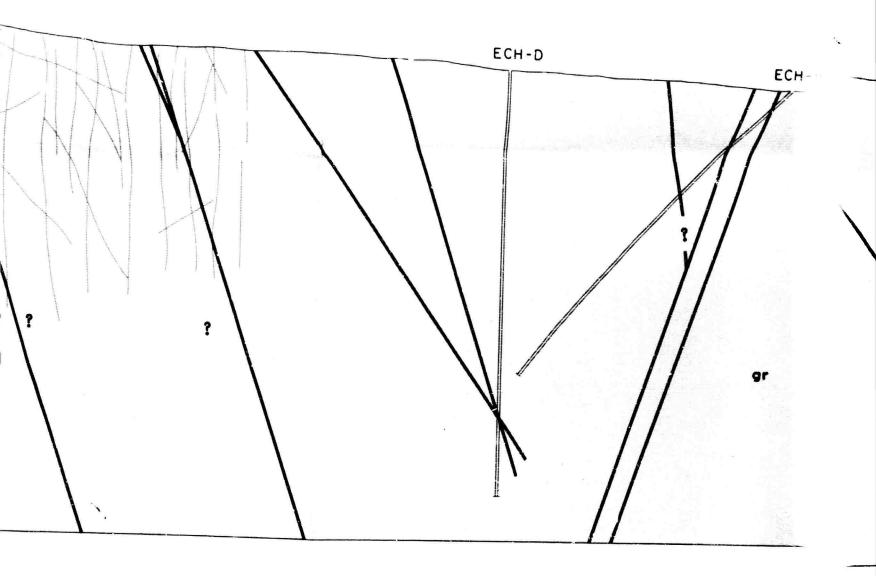
B. Webb, R. Wilson

PLATE 3



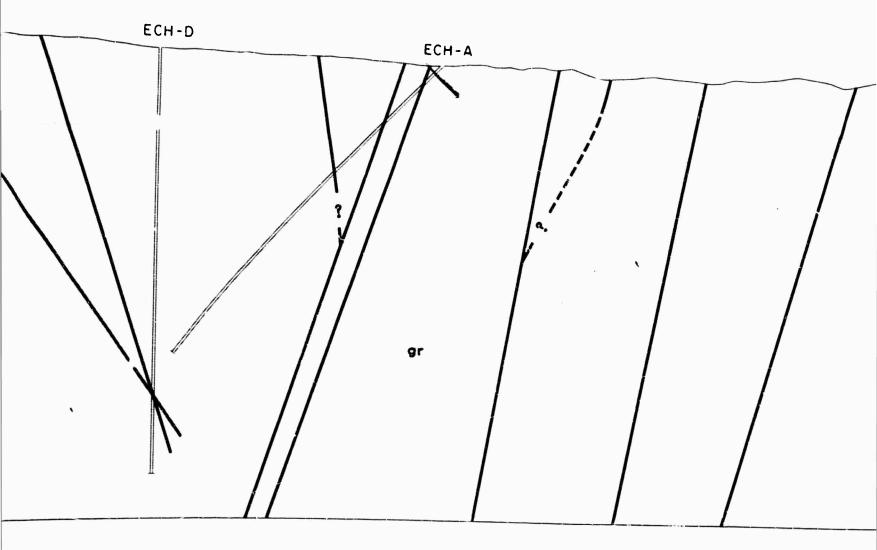
CROSS SECTION

RO

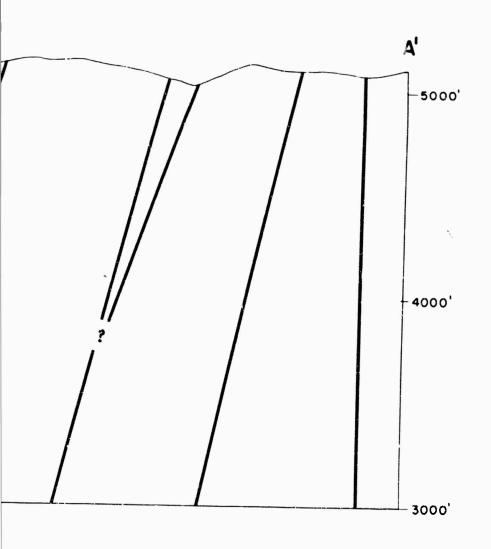


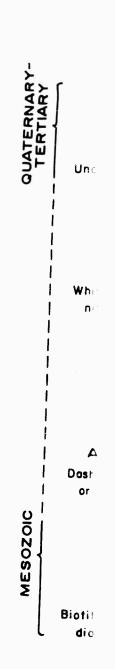


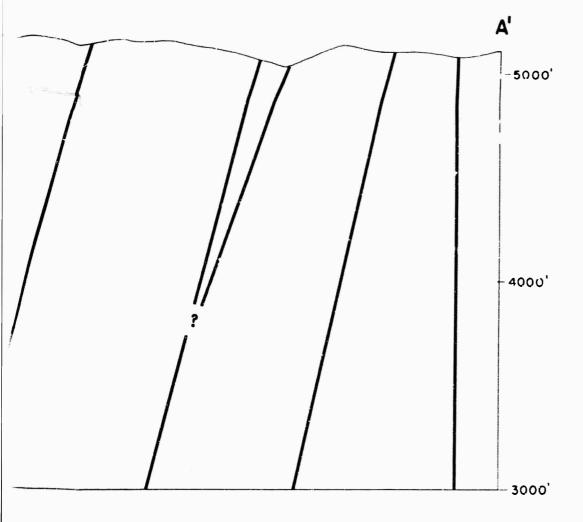
ROSS SECTION



B







MESOZOIC

EXPLANATION

QTs

Sedimentary Rocks Unconsalidated alluvius depasits



Rhyoilte Dikes

White to buff, porphyritic to ophanitic rhyolite



Andesite Dikes

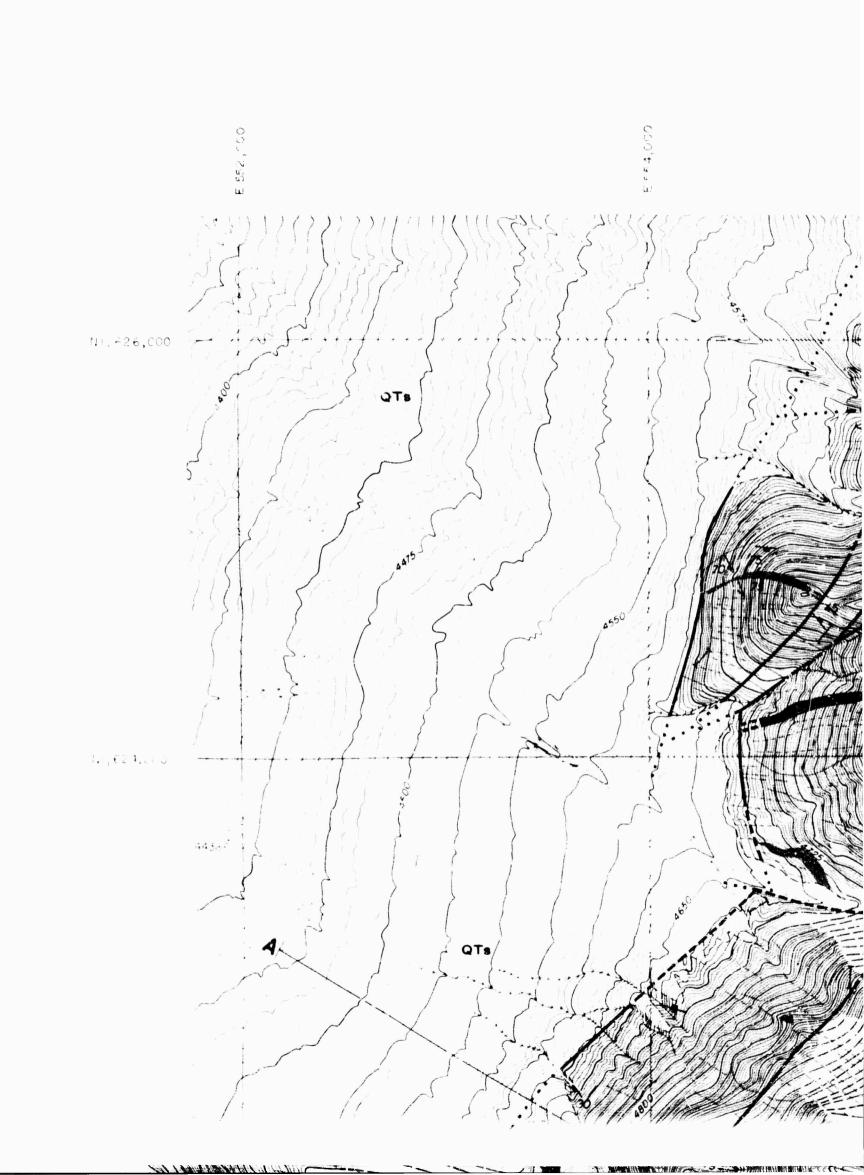
Green-black, porphyritic to ophonitic andesite; and some diabase and diarite

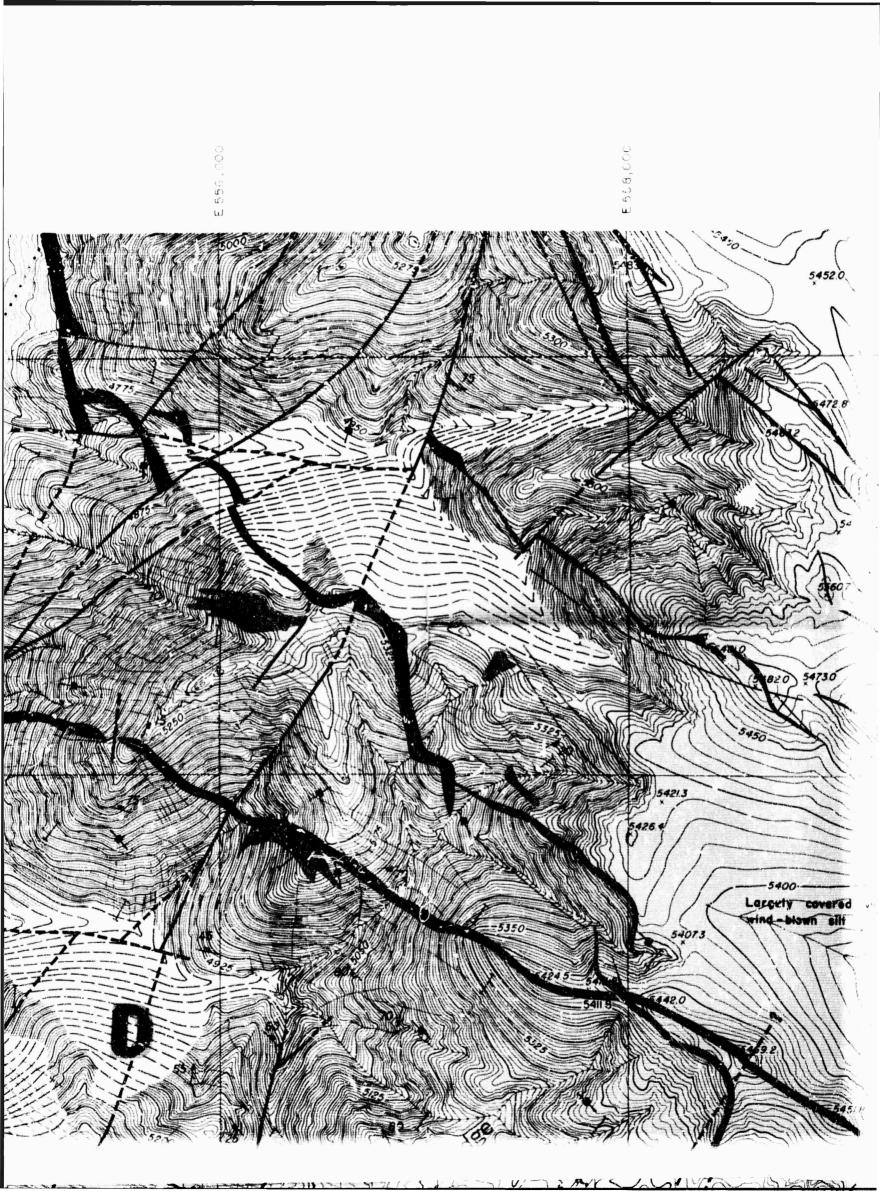
Apilte - Pegmatite Dikes

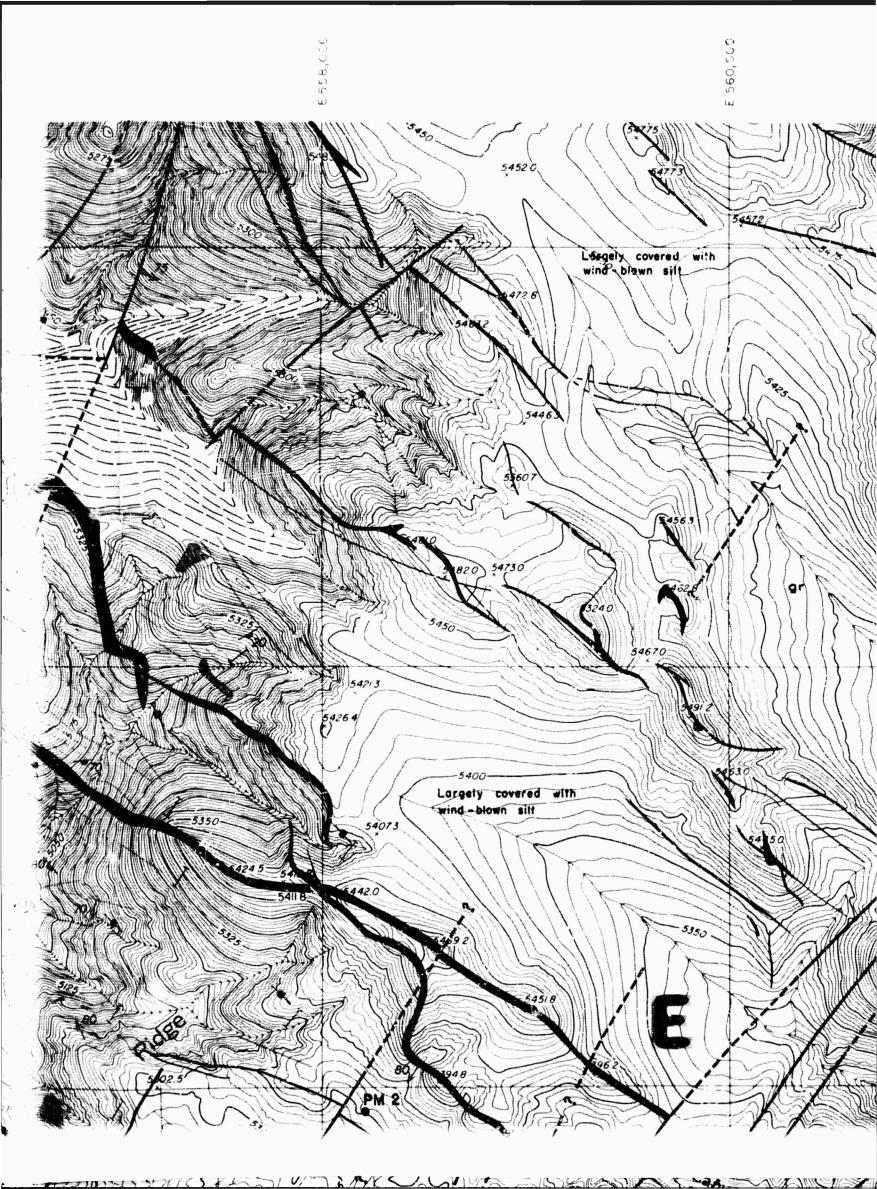
Dashed where approximately lacated or diogrammatic

Granitic Body

Biotite gronite and hornblende gronodiorite





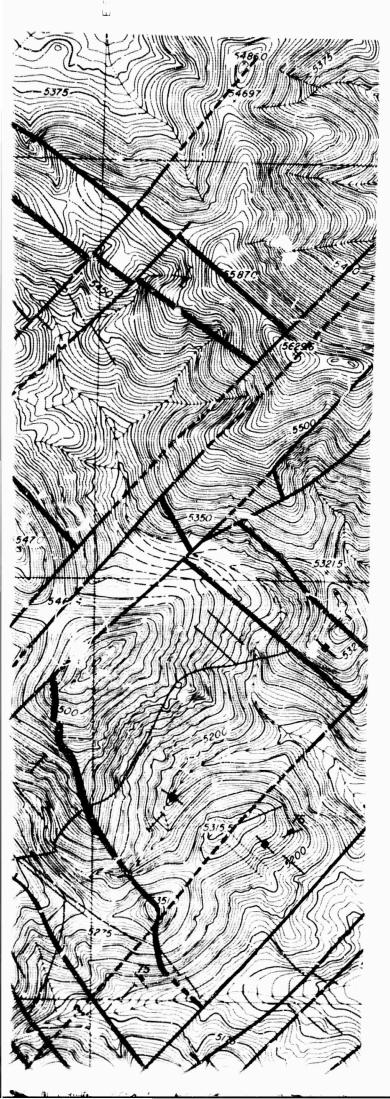


F

the roads of cuts subs

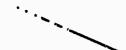
The many c

C



Contact

Dashed where approximately located



High - Angle Fault

Dashed where approximately located dotted where concealed

30 90

trike and Dip of Fracture Cleavage

30 90 • •

Strike and Dip of Joints

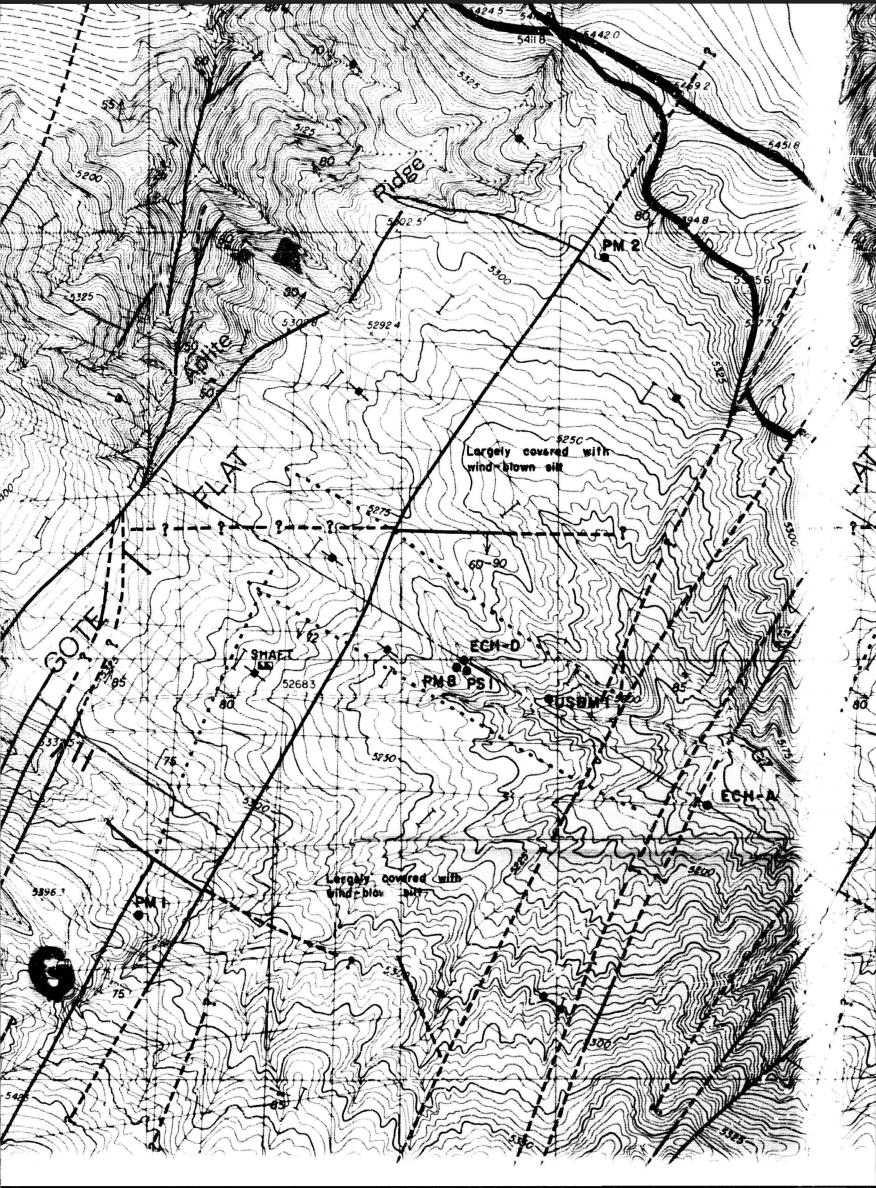
Diamond Drill Hole

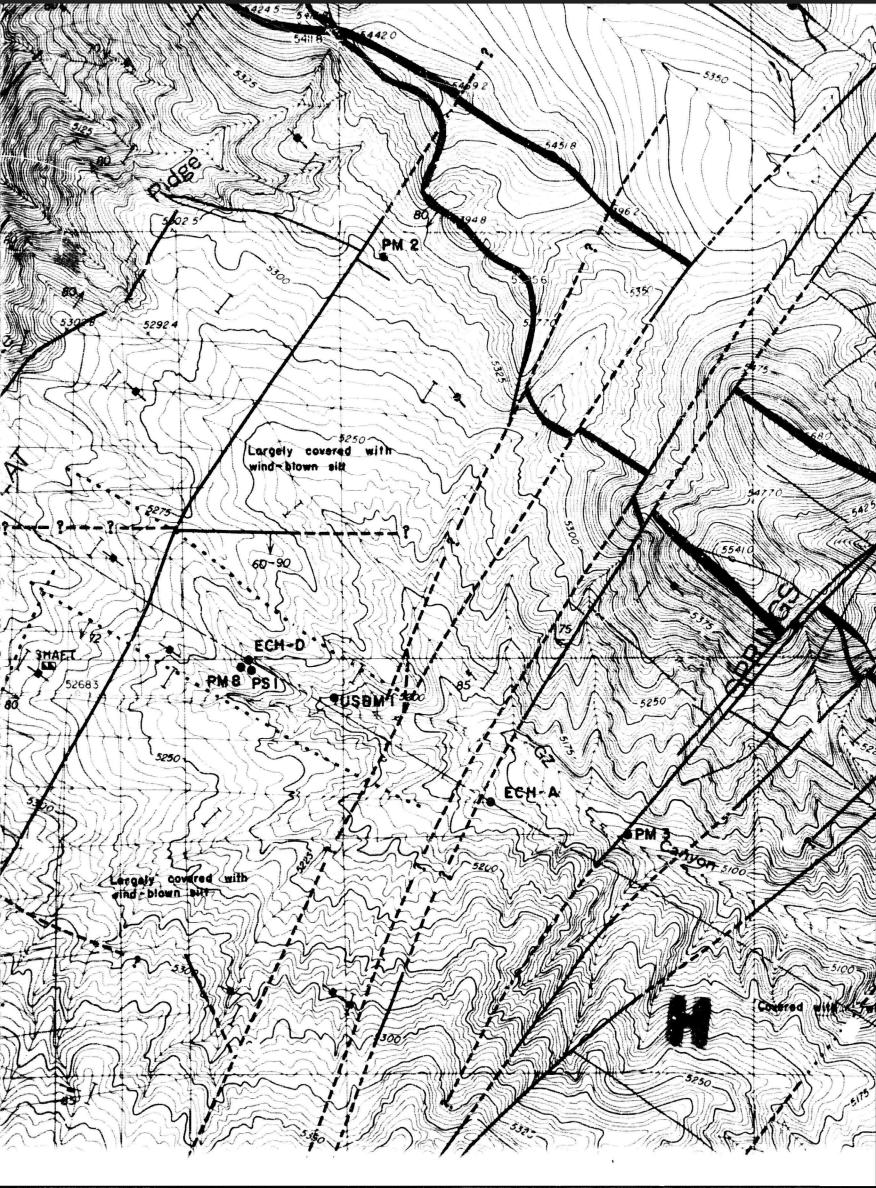
NOTES

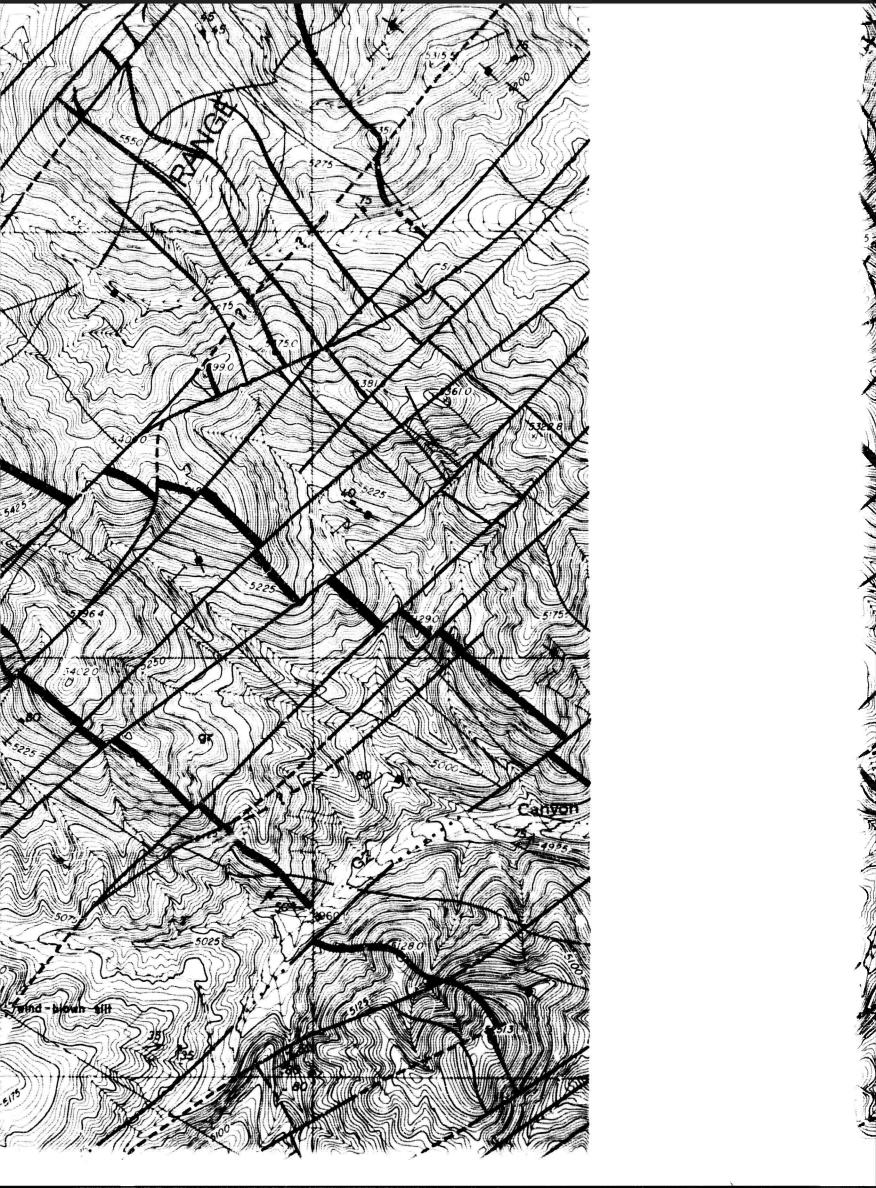
s and buildozer cuts are as of June 1962. No roads or ubsequent to that date have been added.

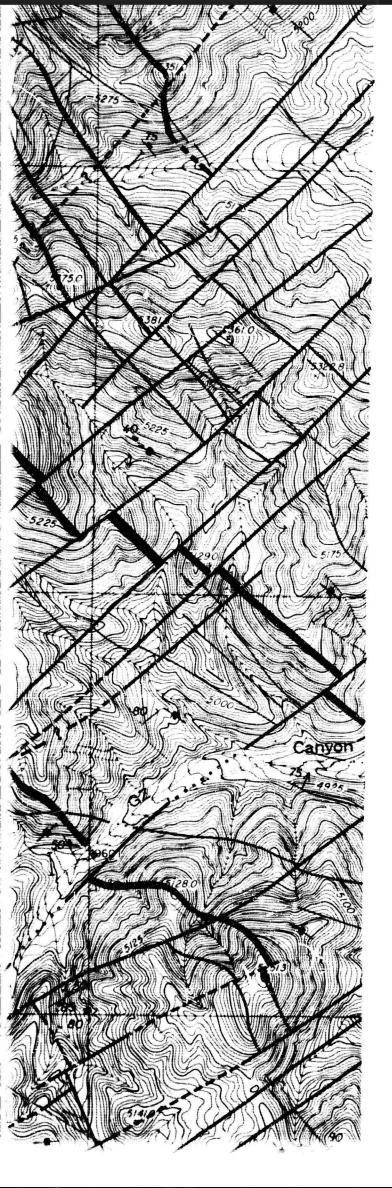
coordinate modifications are too confused to incorporate.











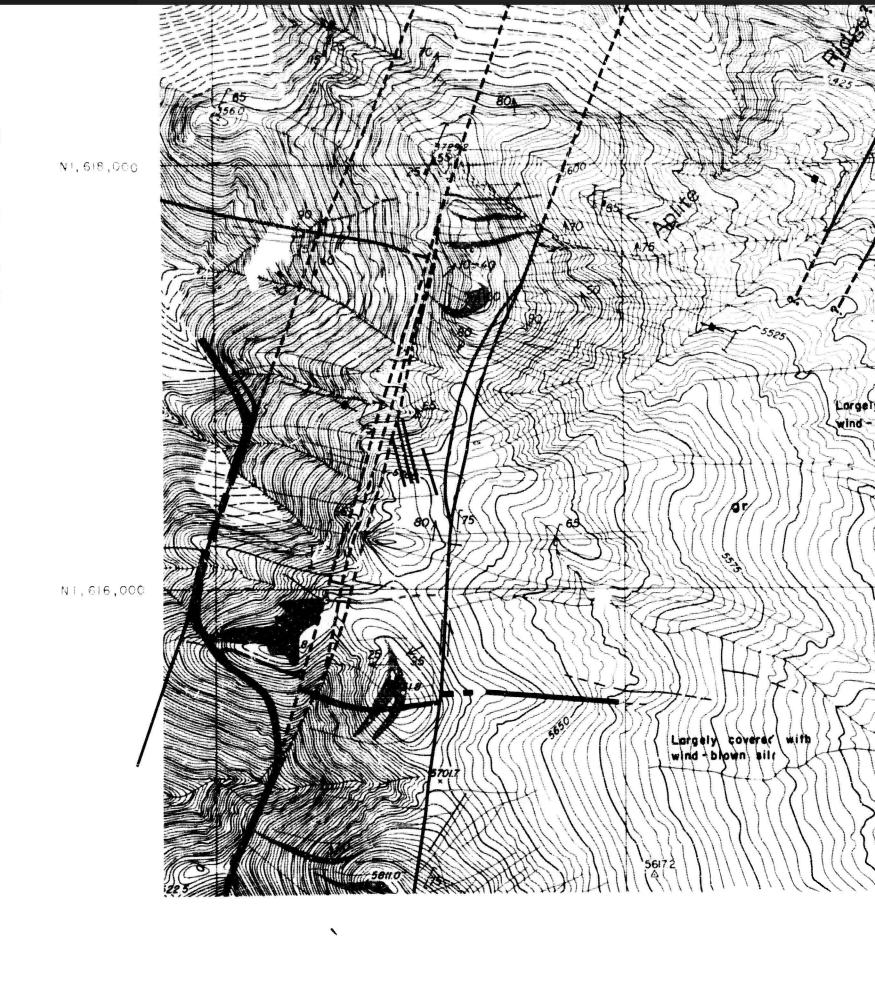
The roads cuts su

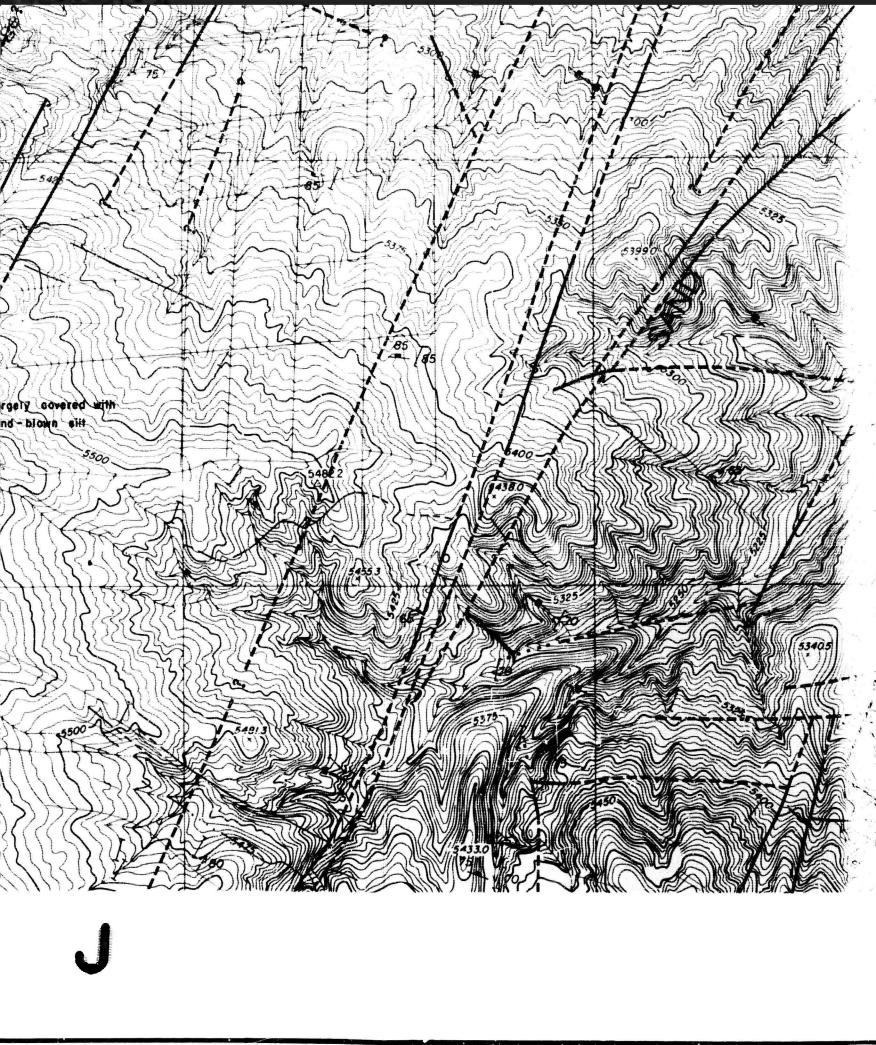
The many
Coording
Engineer
are loca
by coor

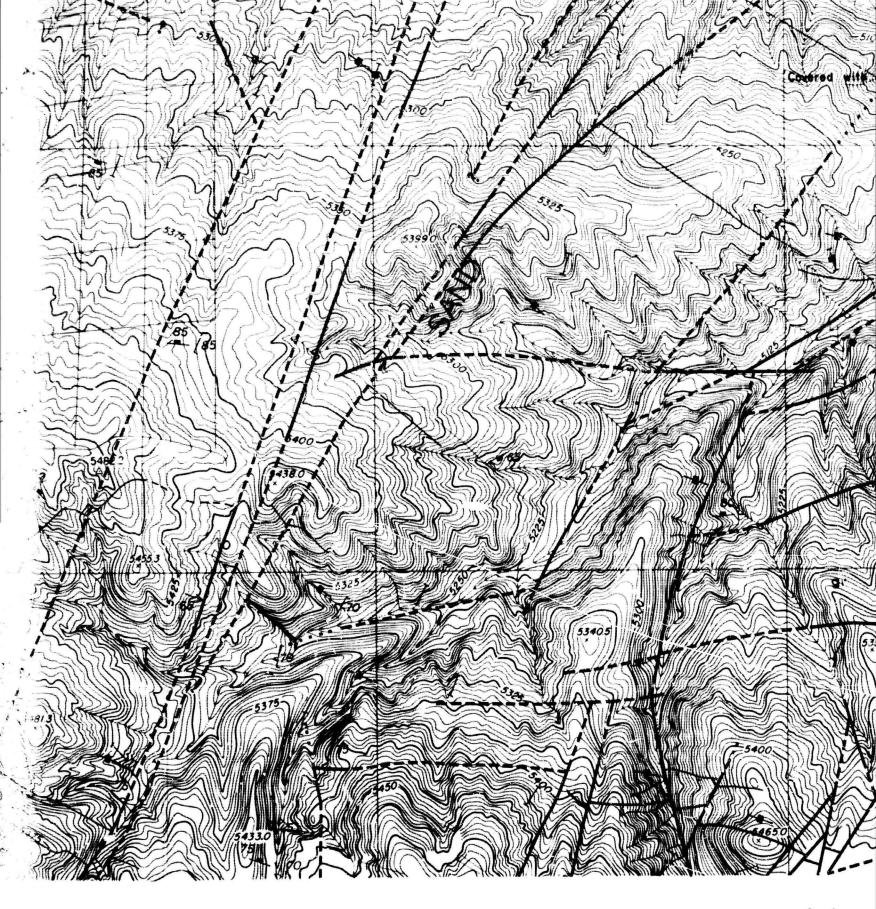
NOTES

ads and bulldozer cuts are as of June 1962. No roads or subsequent to that date have been added.

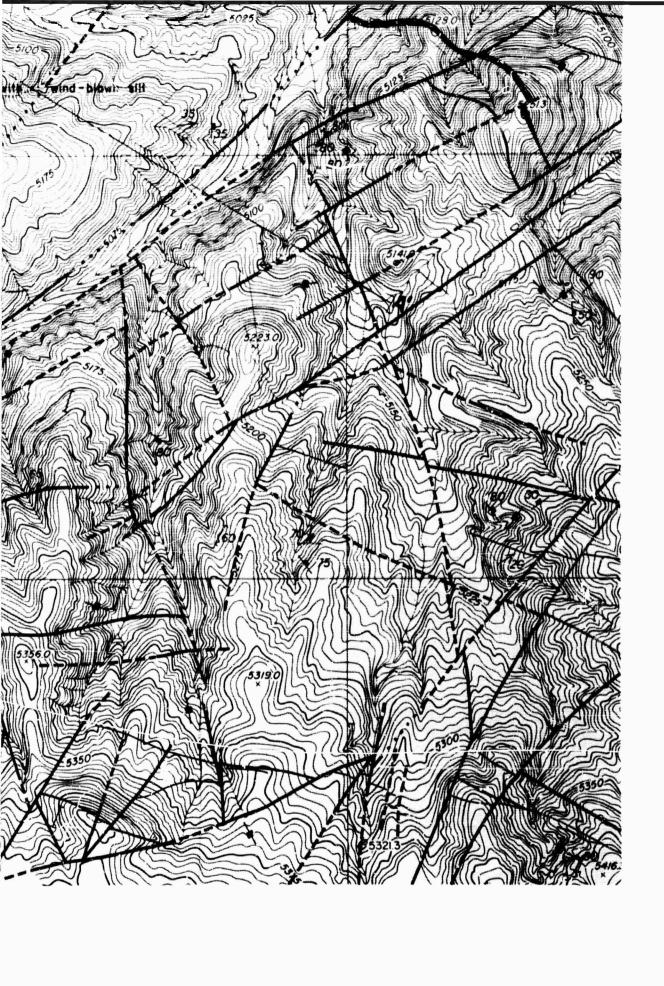
ny coordinate modifications are too confused to incorporate. dinates used here are the original ones assigned by Sprout neers, Inc., and Mark Hurd Aerial Surveys, Inc. Drill holes located to correspond to topography and geology, rather than loordinates, and are in proper geometric relation.

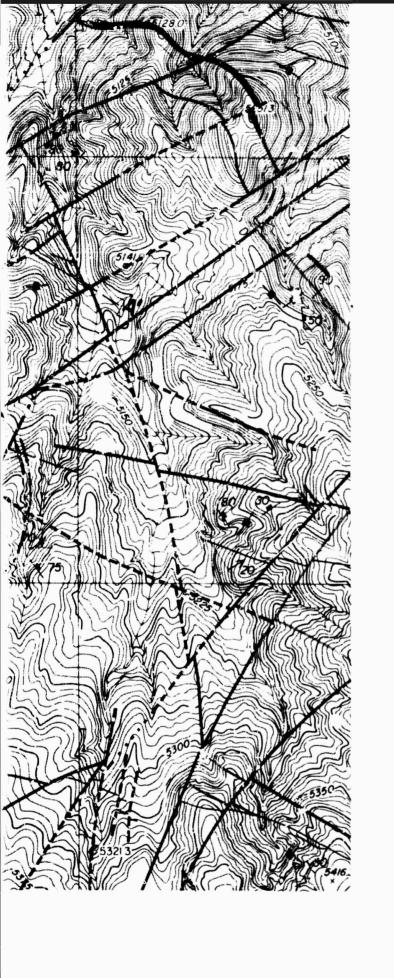






K

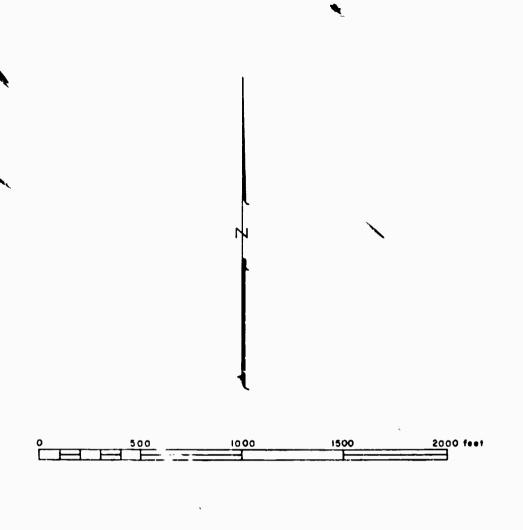




MACKAY

SCALE

ENGINEERING COTOPORTHER COLOGIC MAP CARTOGRAPHY REVISED



NEVADA BUREAU OF MINES

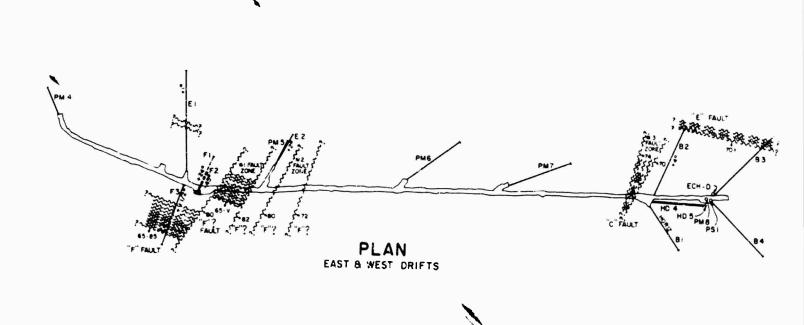
KAY SCHOOL OF MINES

UNIVERSITY OF NEVADA

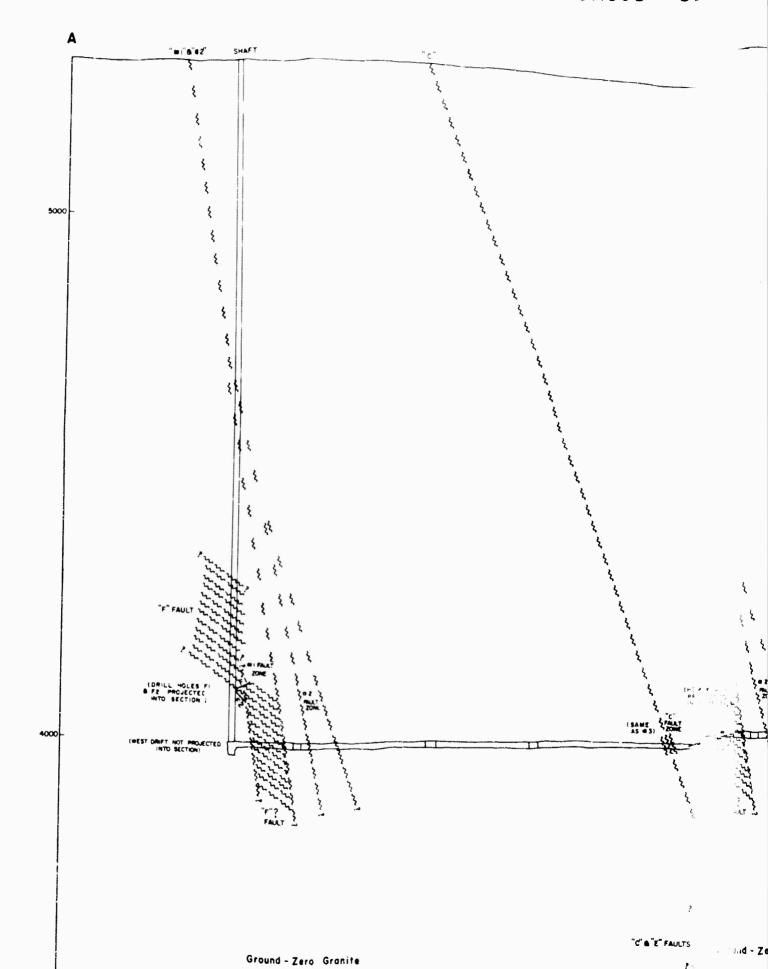
GEOLOGIC MAP AND SECTION AREA B (GROUND ZERO AREA)

CHURCHILL COUNTY, NEVADA

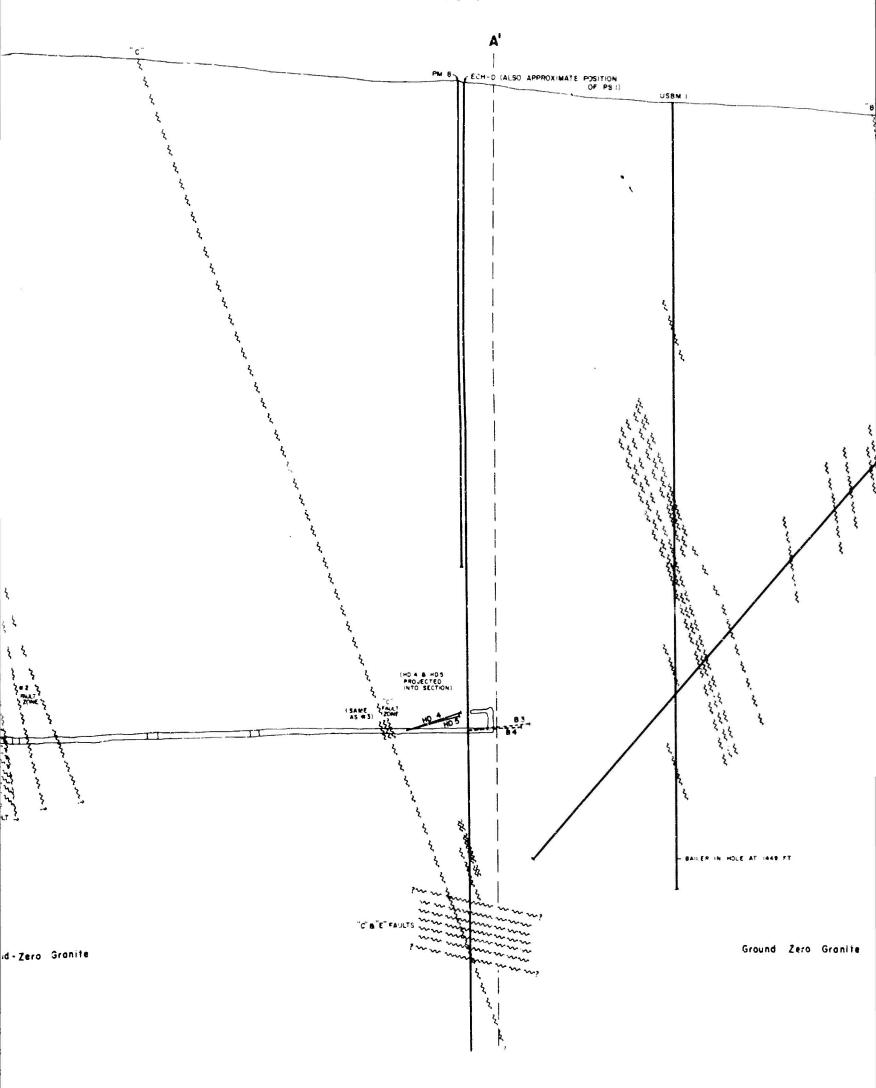
E 1:6,000	DATE: SEPTEMBER 1962
G CONTROL	Sprout Engineers, Inc.
Y	Mork Huid Aeriol Surveys, Inc.
MAPPING	NBM personnel: L. Beal, S. Jerome, J. Schilling
НҮ	A. Webb, R. Paul
	September 1964

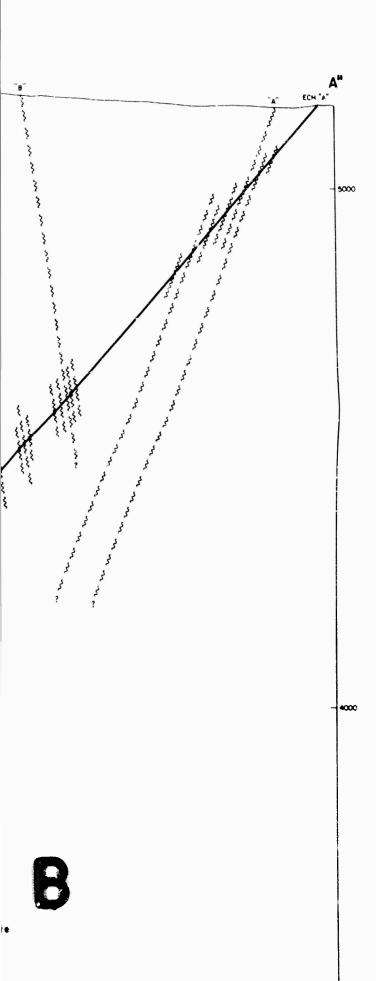






CROSS SECTION

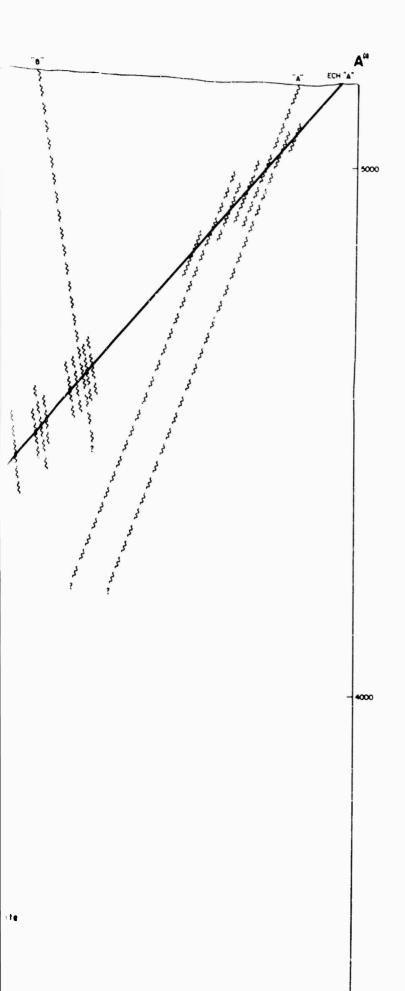




•

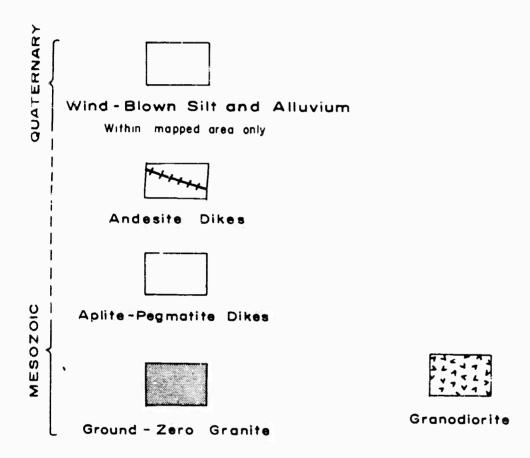
ite

118



C

EXPLANATION



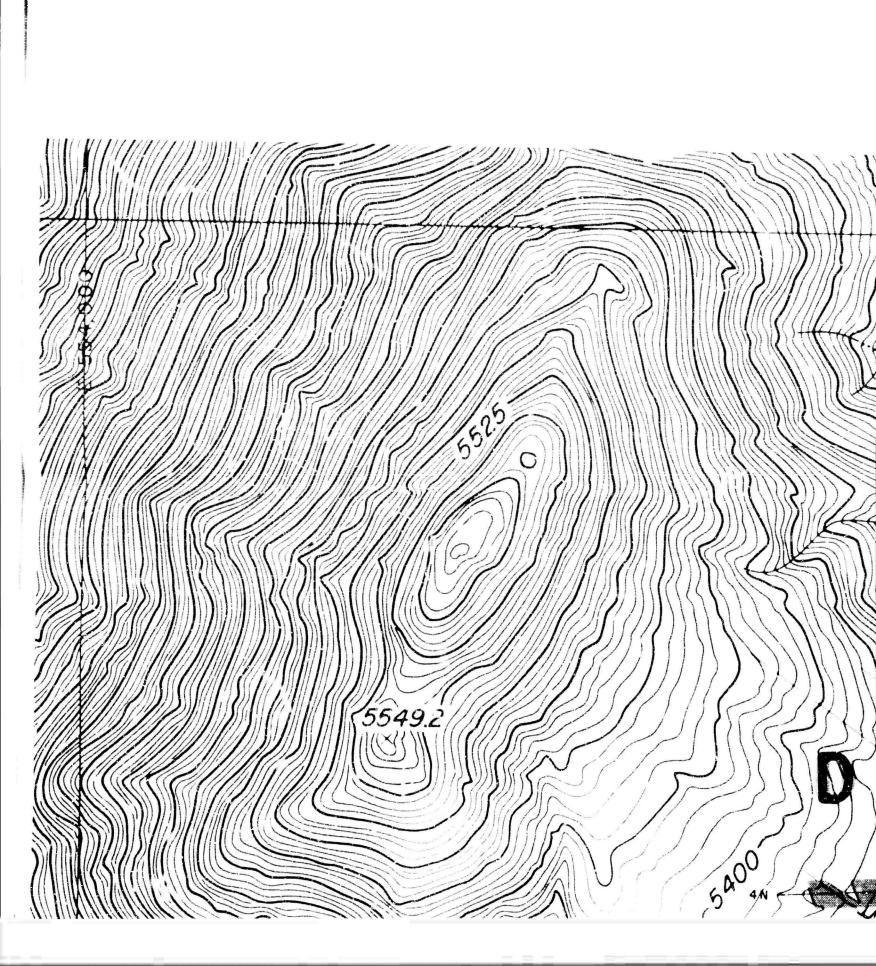
Contact

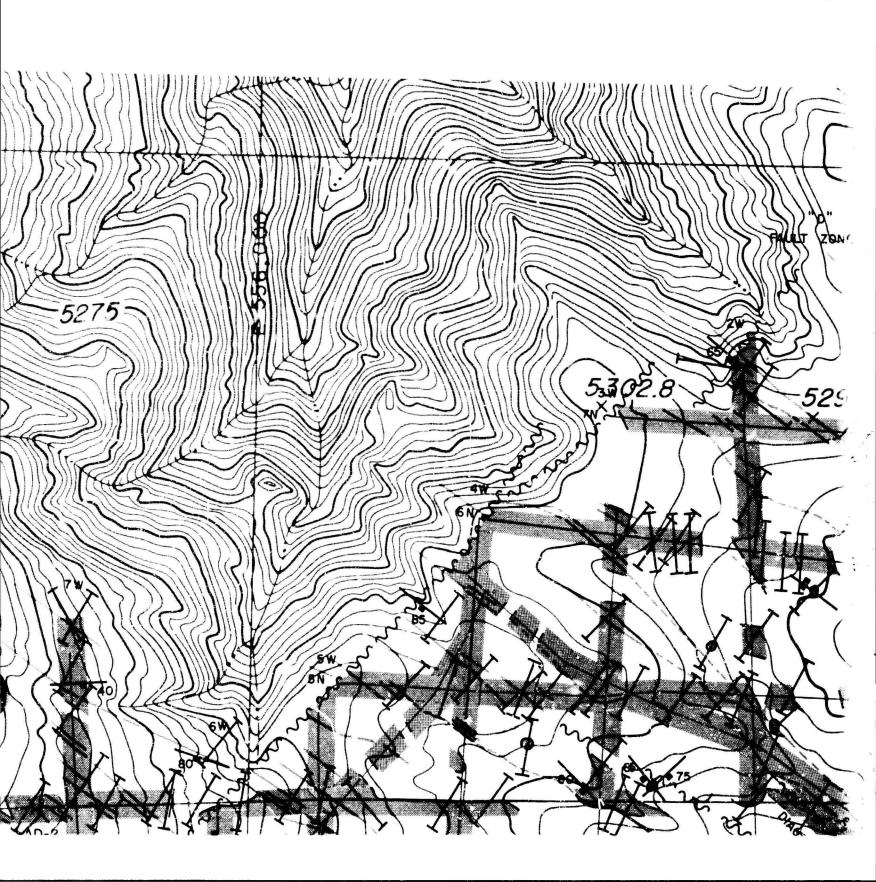
Dashed where approximately located

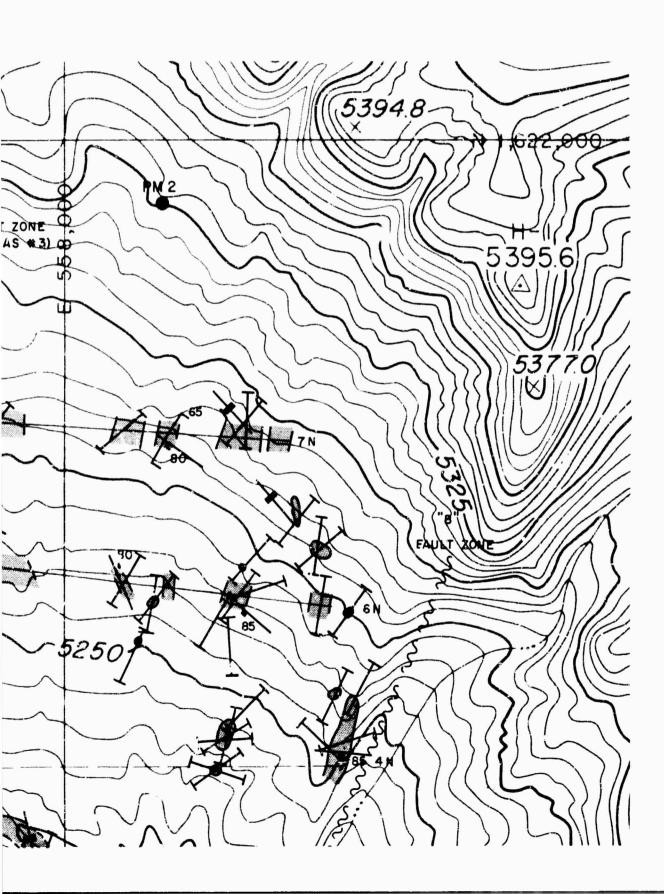
High - Angle Fault

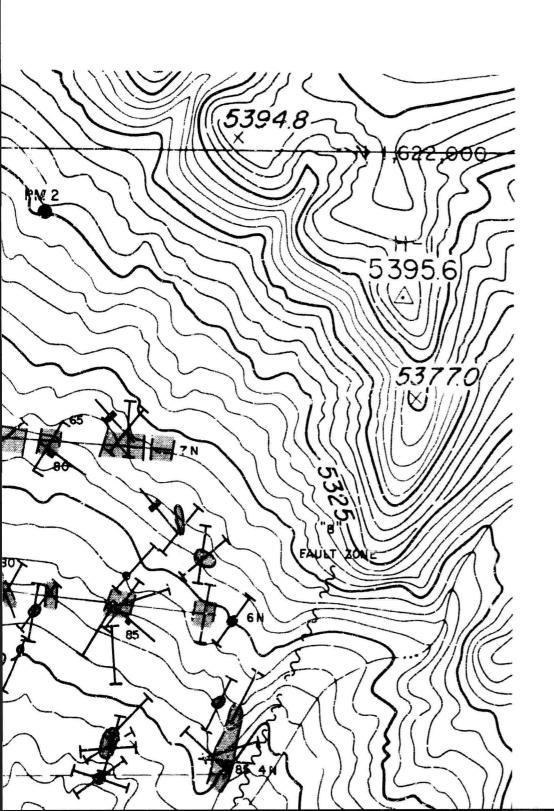
Dashed where approximately located or conceoled

30 90









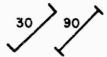
Territories de la constitución d

was at

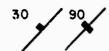
High - Angle Fault

Dashed where approximately located

or concealed



Strike and Dip of Fracture Cleavage



Strike and Dip of Joints

Diamond Drill Hole

X

Age Determination Sample

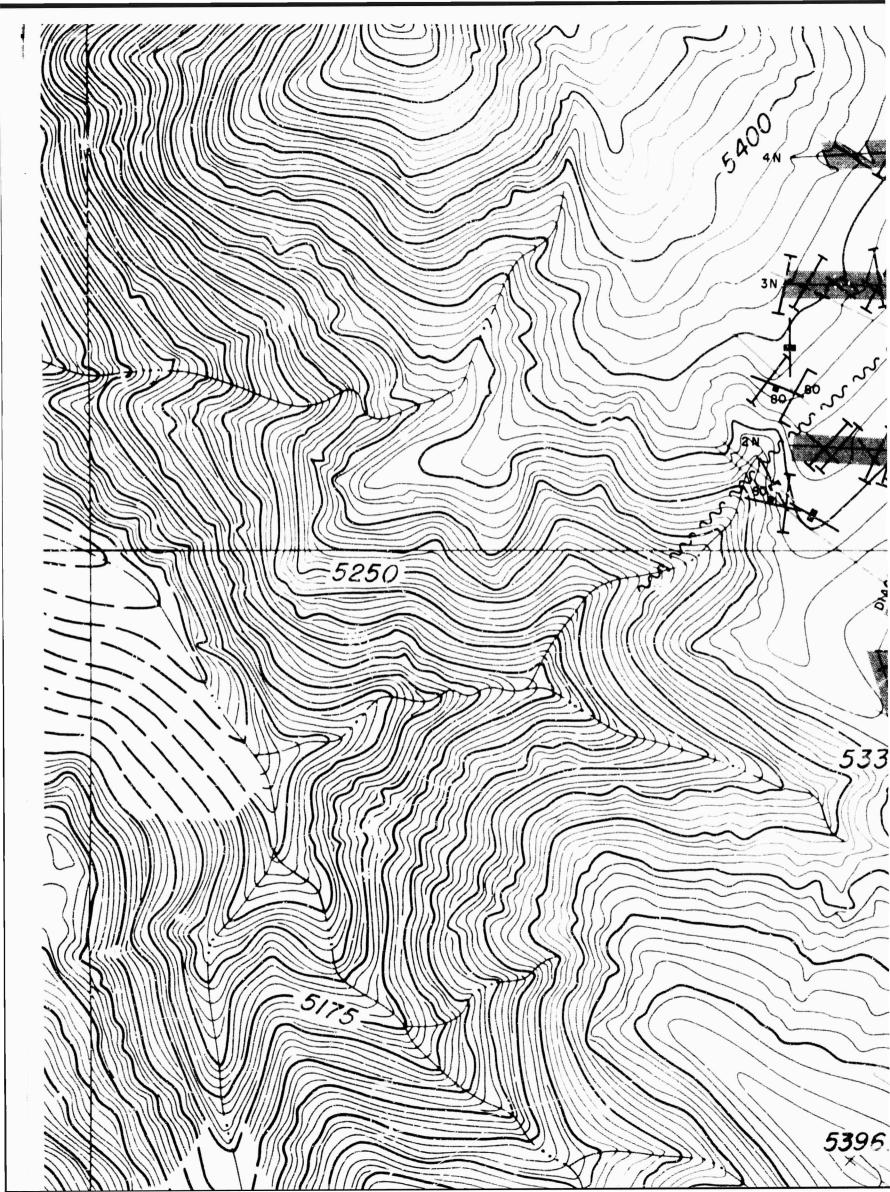
AD-1 of granite; AD-2, AD-6 of aplitepegmatite dike

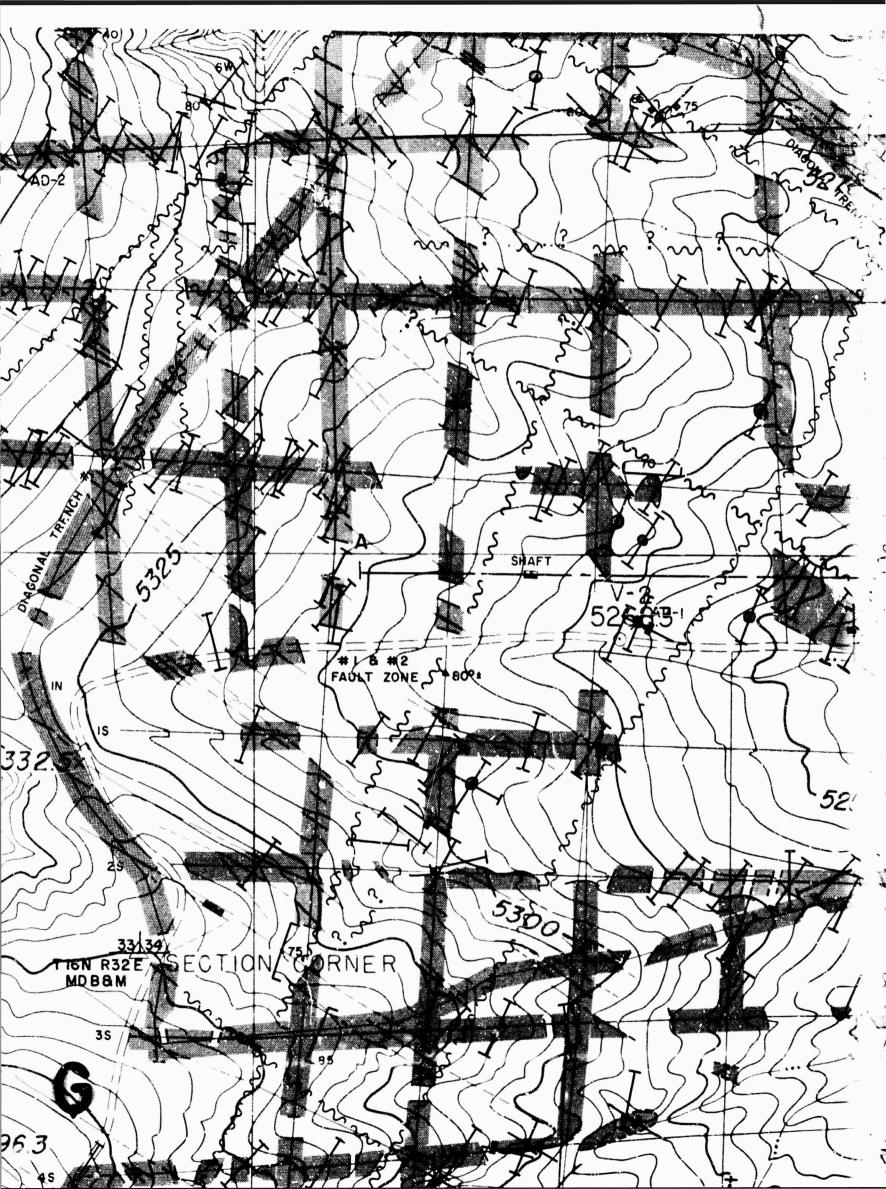
Trench

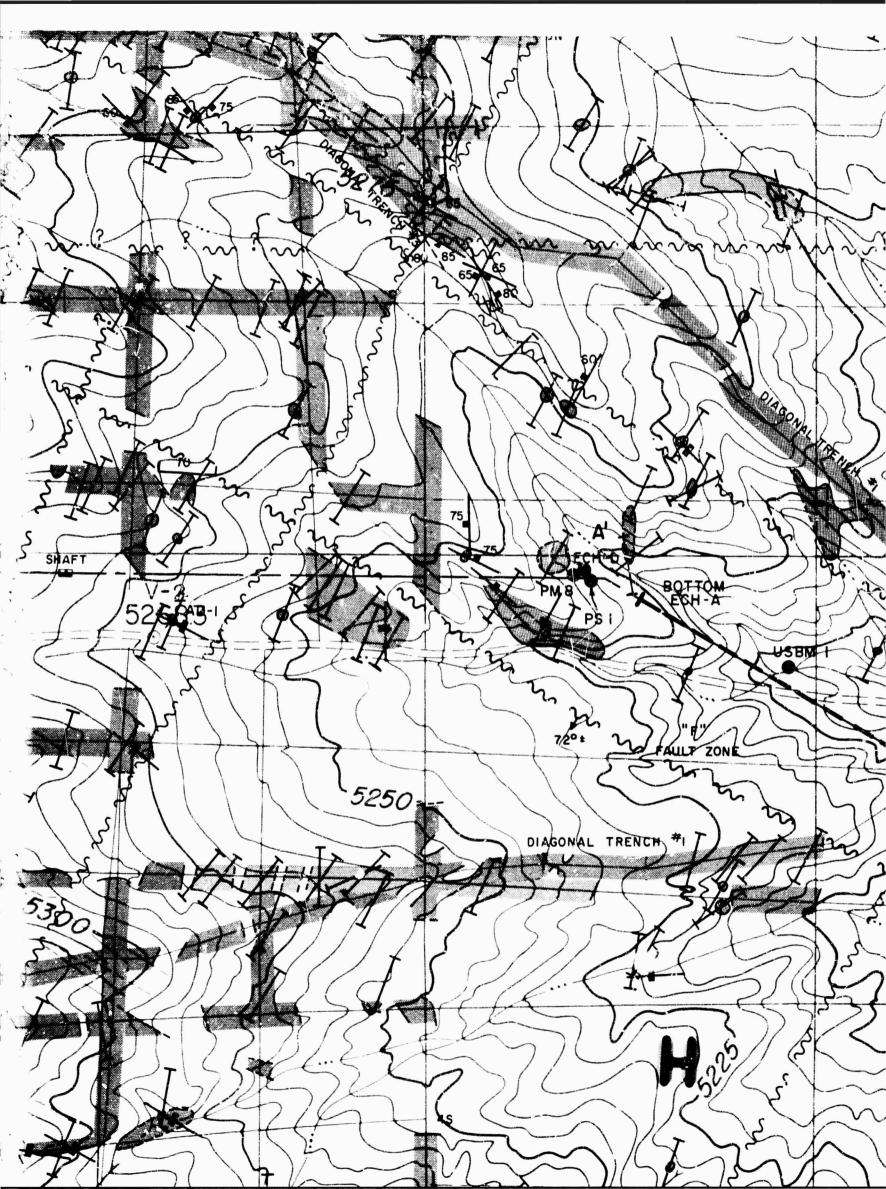
Supplementary Traverse
Not trenched

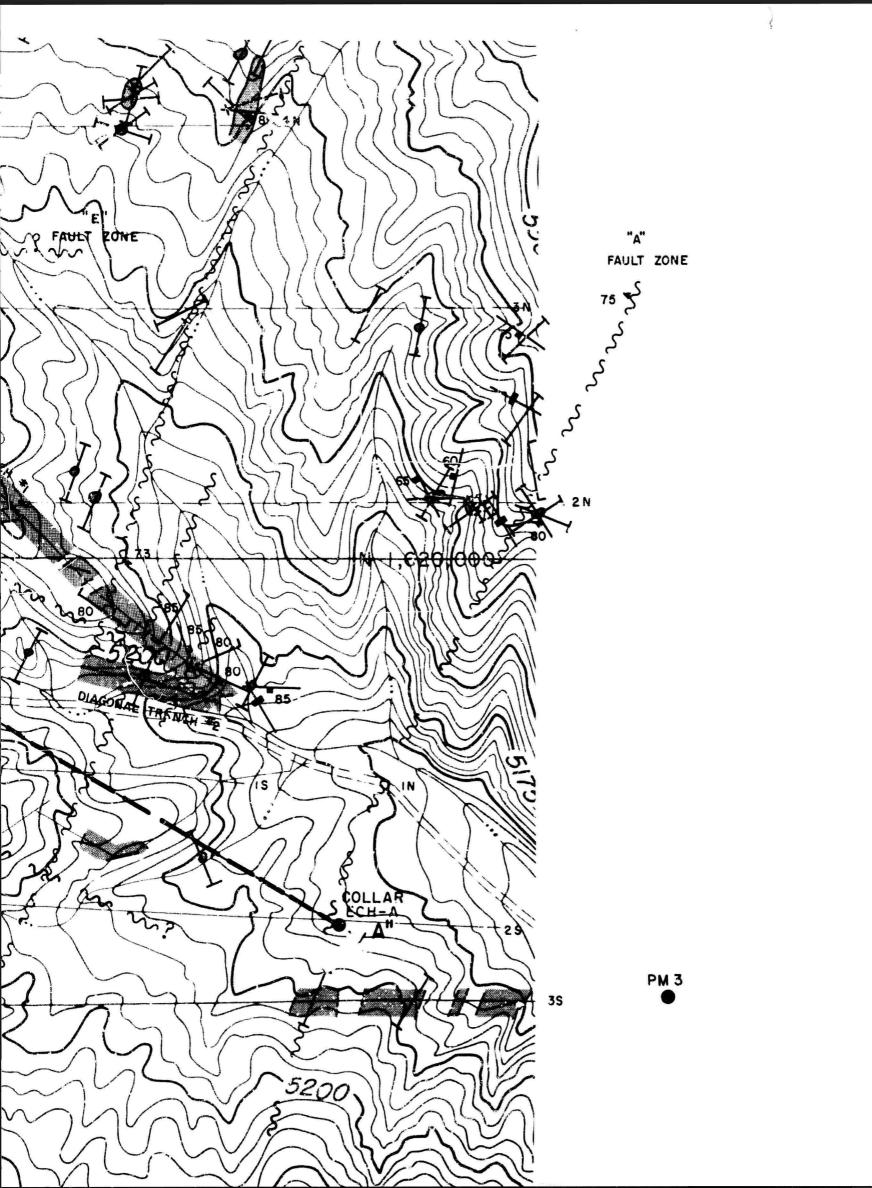
NOTES

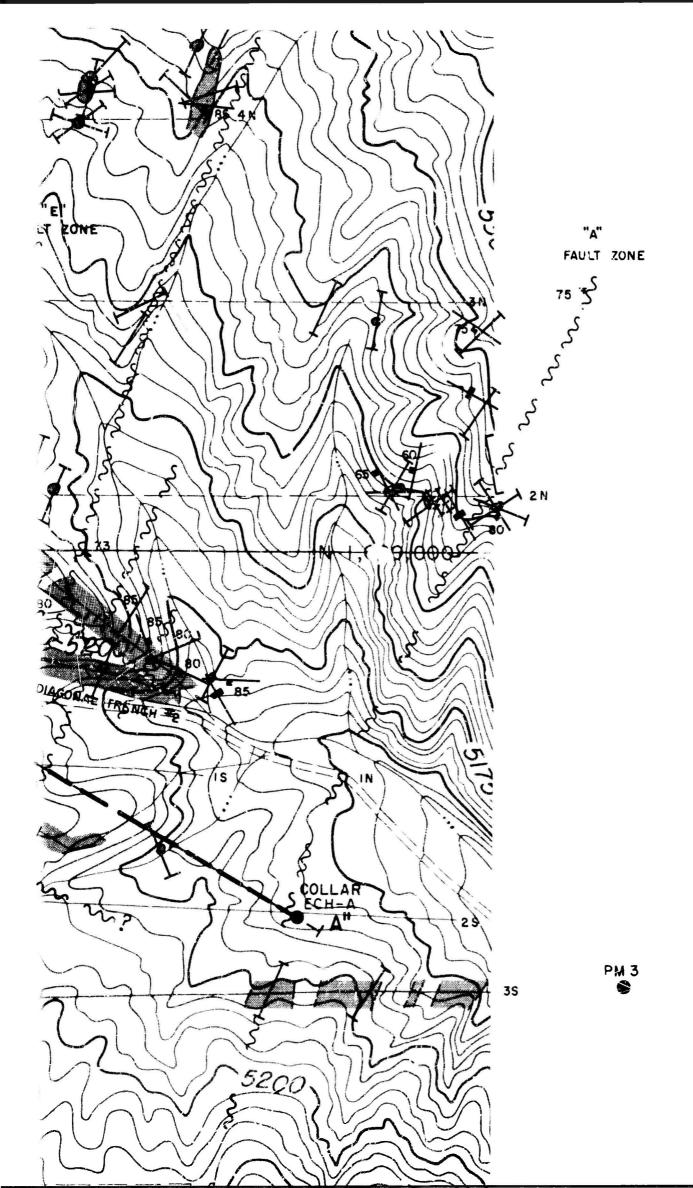
Drill holes ECH-D and USBM I are shown projected into the plane of the cross section.





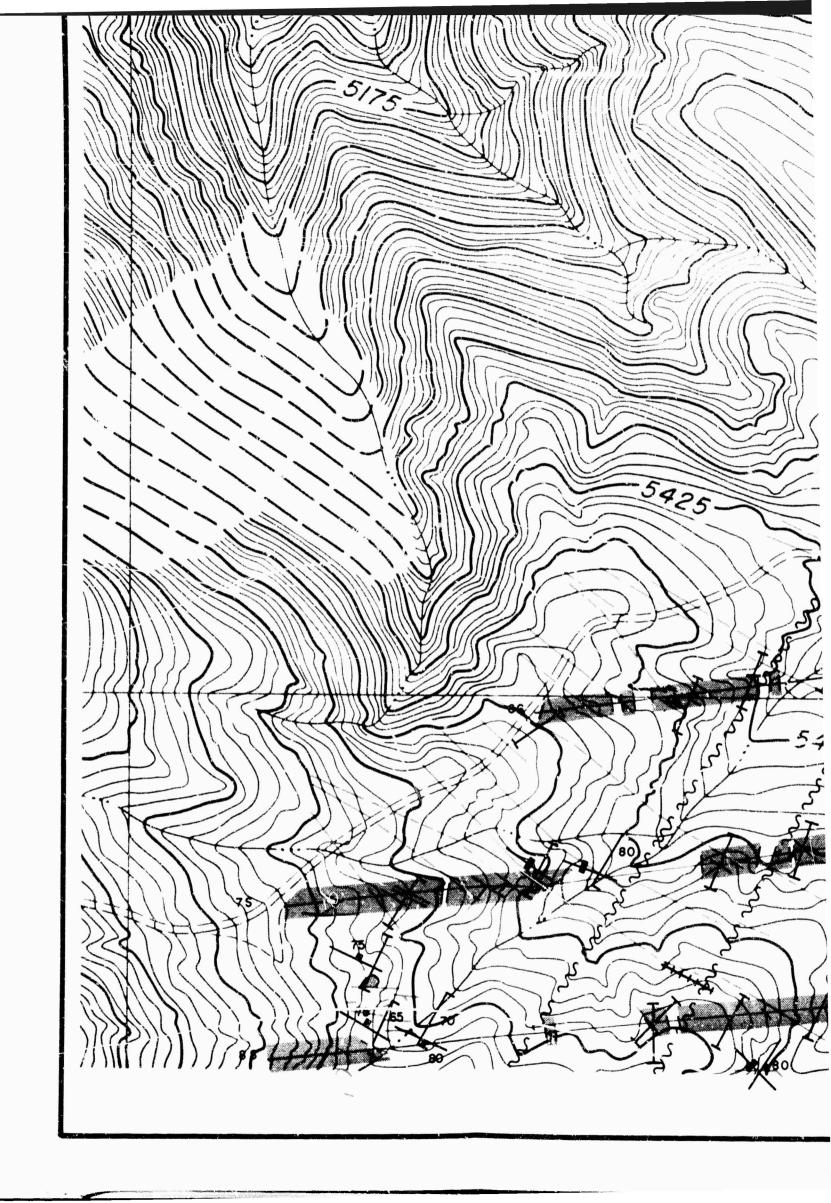


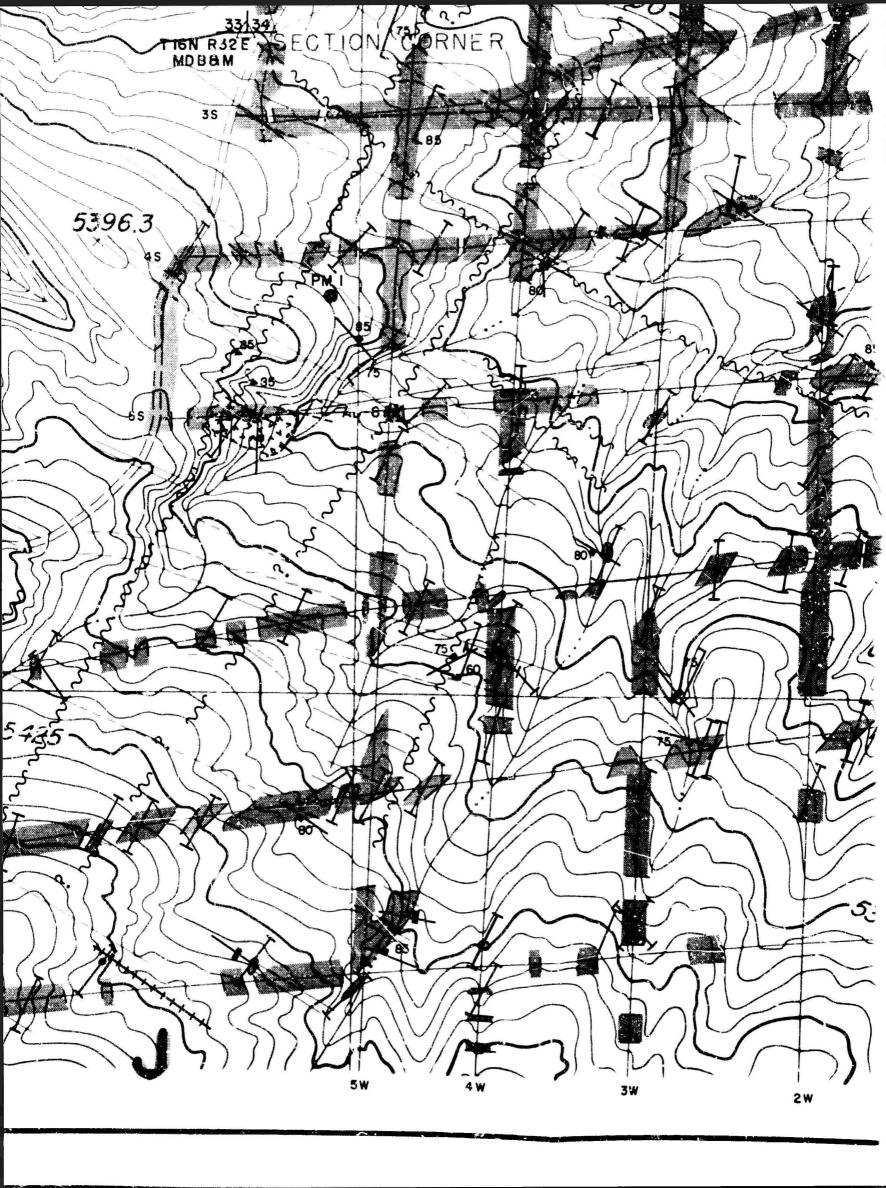


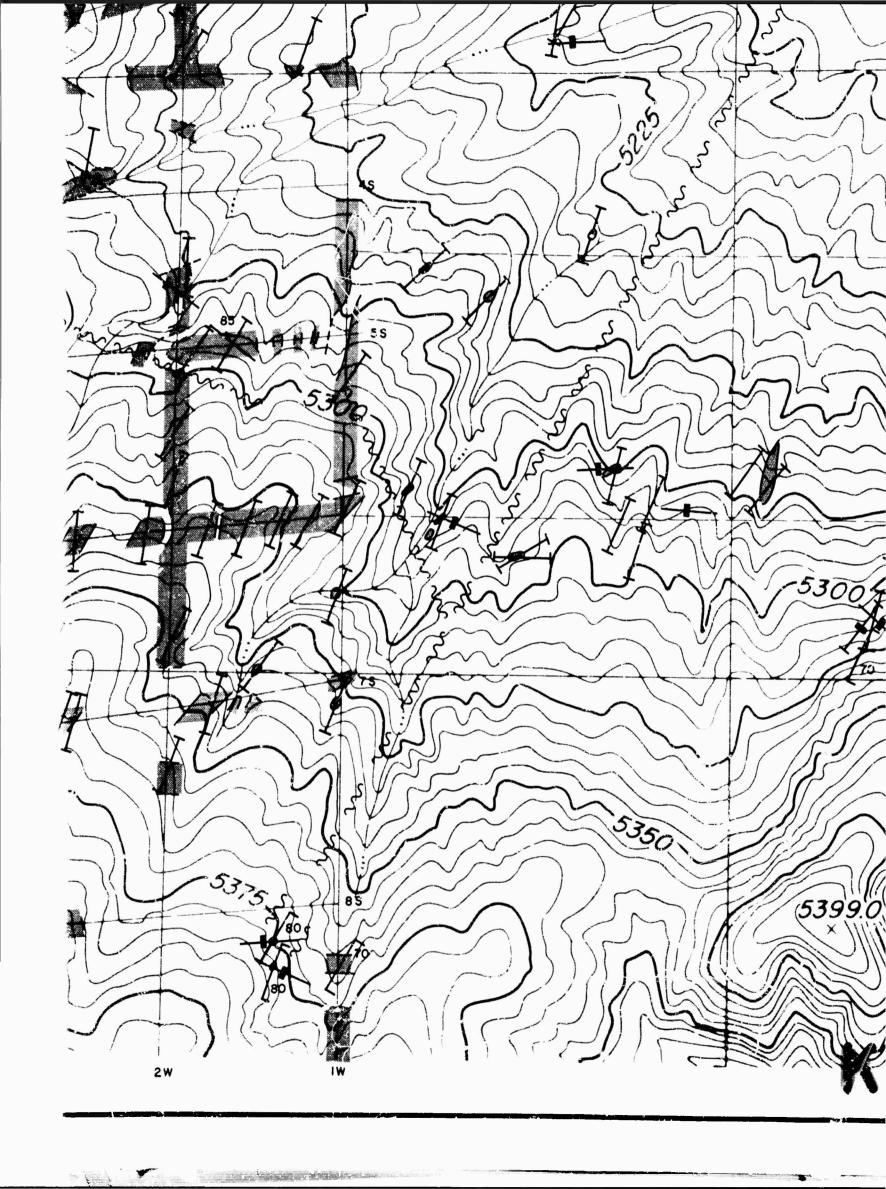


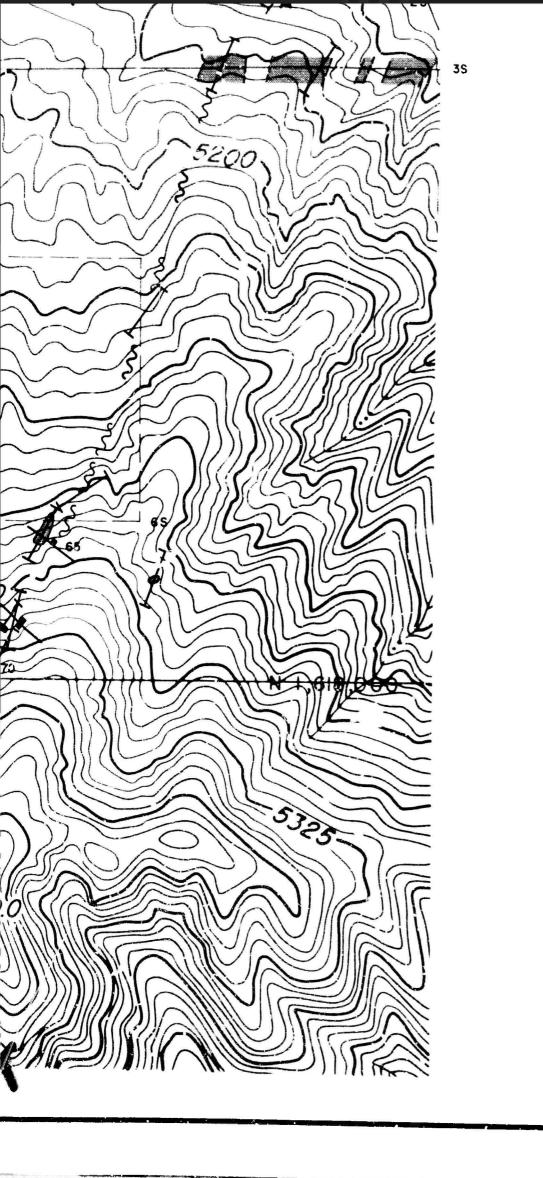
- Drill holes ECH-D and USBM I are shown projected into the plane of the cross section.
- The roads and bulldozer cuts are as of June 1962. No roads or cuts subsequent to that date have been added.
- The many coordinate modifications are too confused to incorporate.

 Coordinates used here are the original ones assigned by Sprout Engineers, Inc., and Mark Hurd Aerial Surveys, Inc. Drill holes are located to correspond to topography and geology, rather than by coordinates, and are in proper geometric relation.









PM 3

AM

SCA', a

TOPOGRA GEOLOGI

CARTOGR

3\$ 5200 5325.

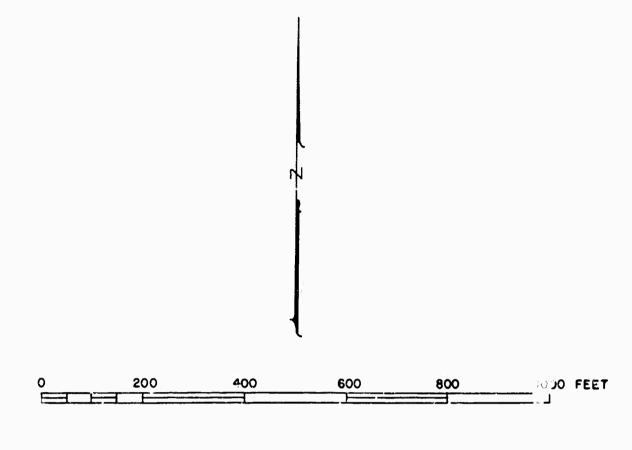
MACKAY S

SCALE

ENGINEERING CONT

TOPOGRAPHY GEOLOGIC MAPPIN

CARTOGRAPHY



NEVADA BUREAU OF MINES

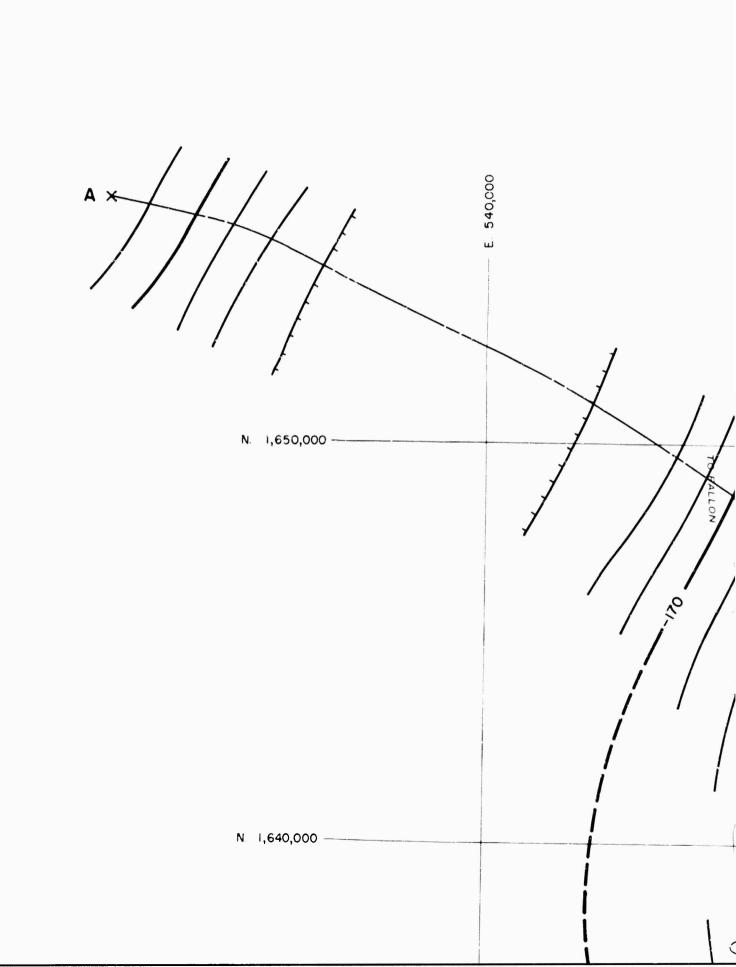
Y SCHOOL OF MINES

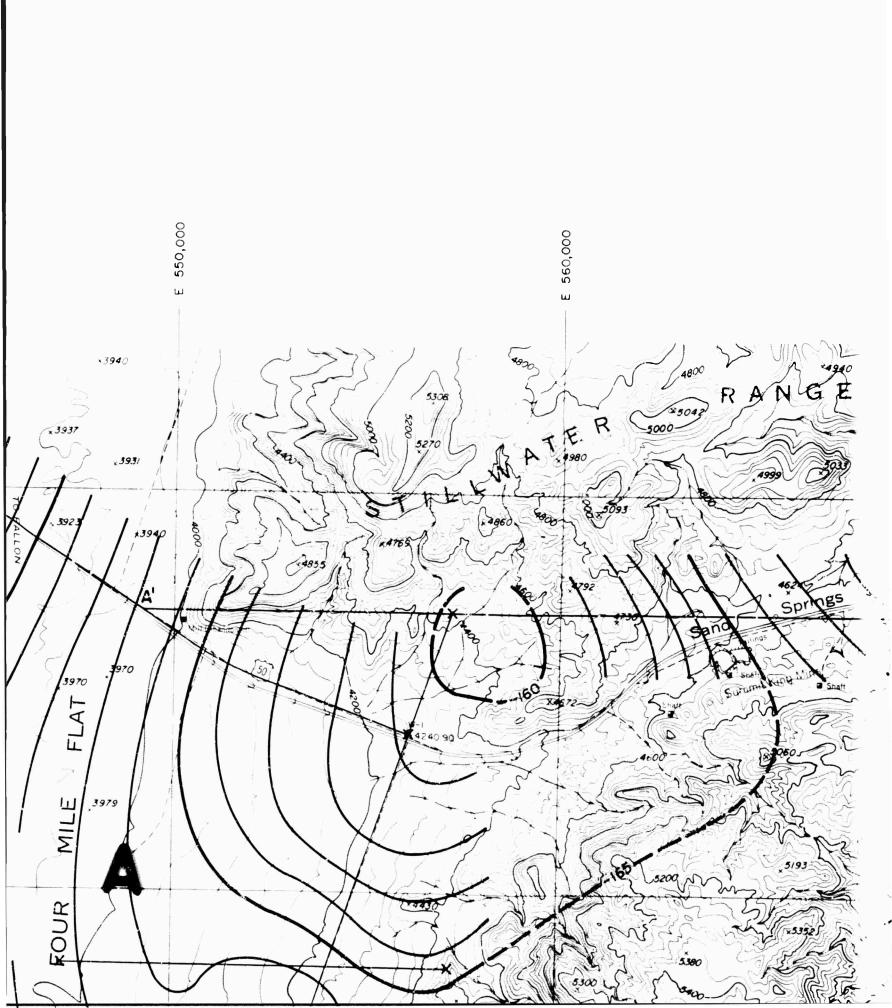
UNIVERSITY OF NEVADA

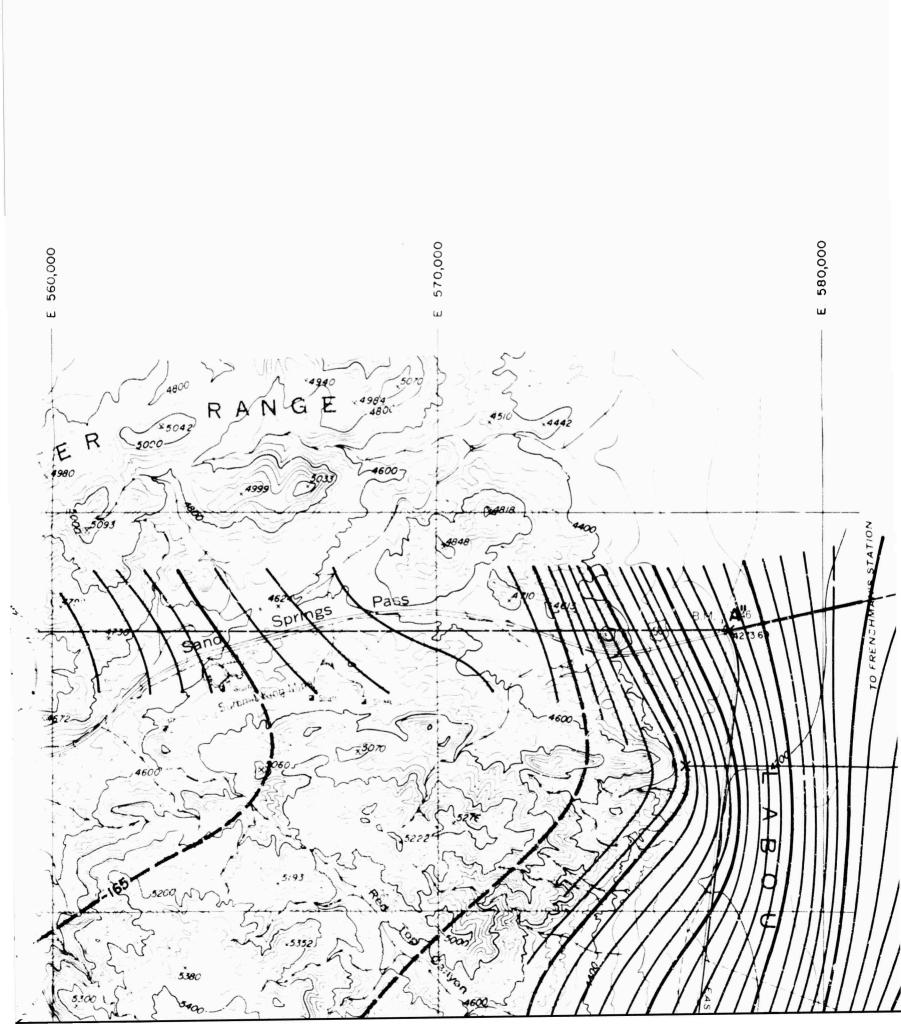
DETAILED GEOLOGIC MAP AND SECTION AREA B (GROUND ZERO AREA)

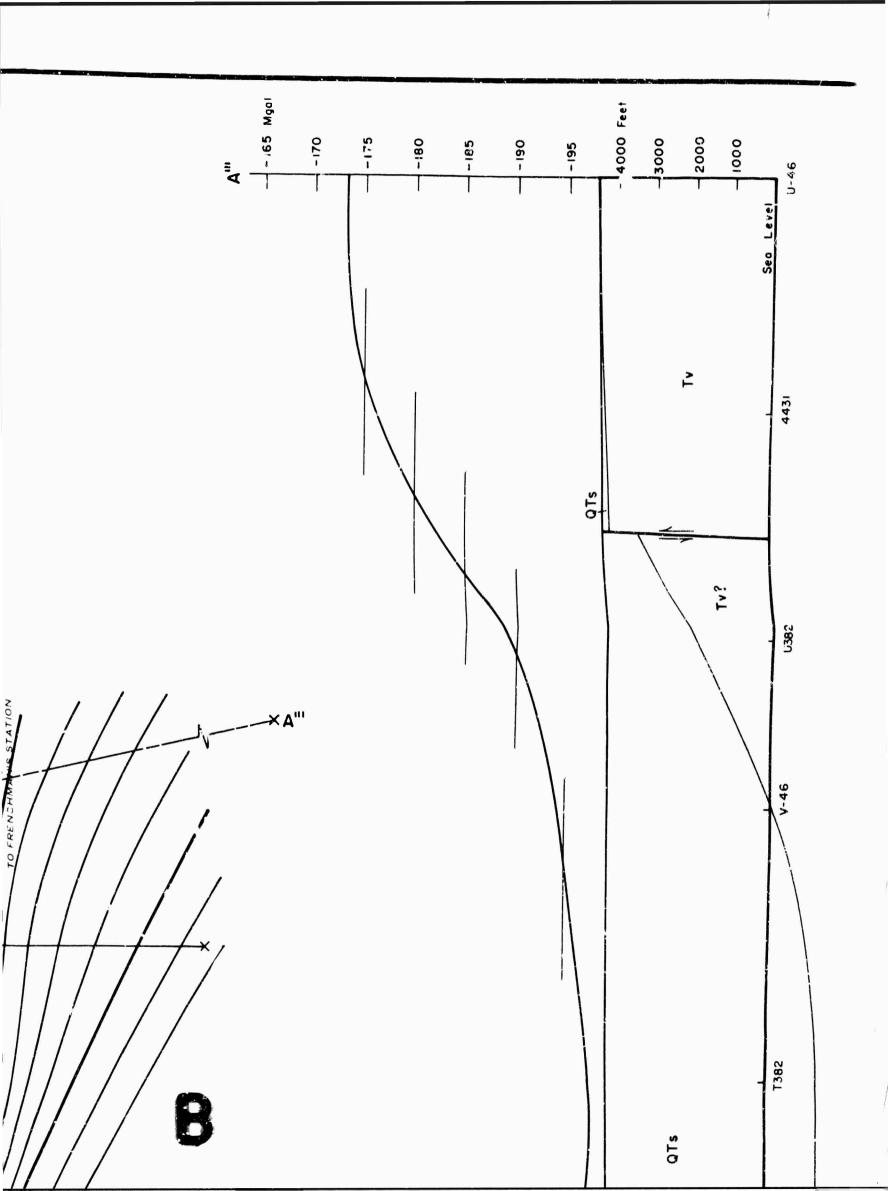
CHURCHILL COUNTY, NEVADA

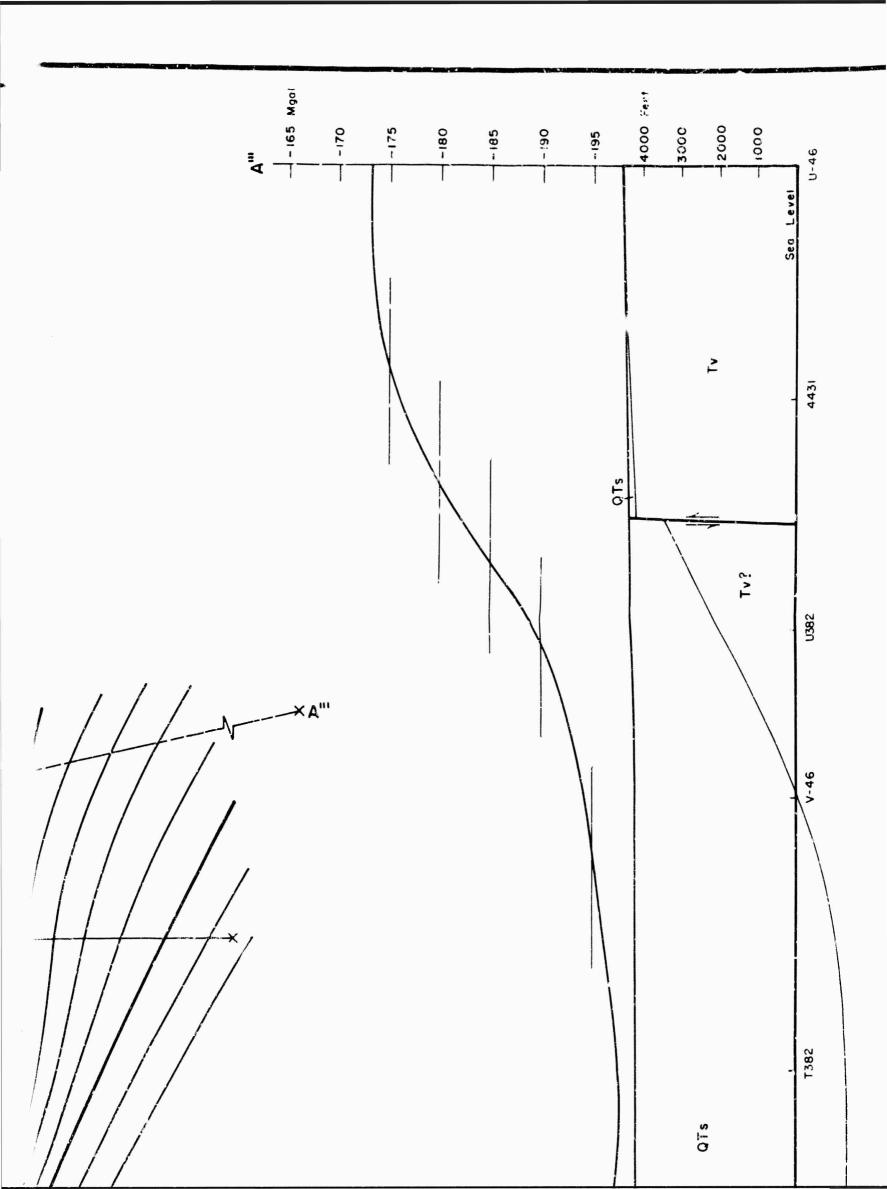
1:2,40	00 C. 1. 5 feet	DATE: SEPTEMBER 1962
CONTROL	Sprout Engineers, Inc.	
	Mark Hurd Aerial Surveys, Inc.	
PPING	NBM personnel: L. Beal, R.	Harton, S. Jerome, I. Lutsey, R. Olson, J. Schilling,
	L. Agenbroad. Drift Geology by	
	R. Wijson, R. Poul	REVISED: September 1964

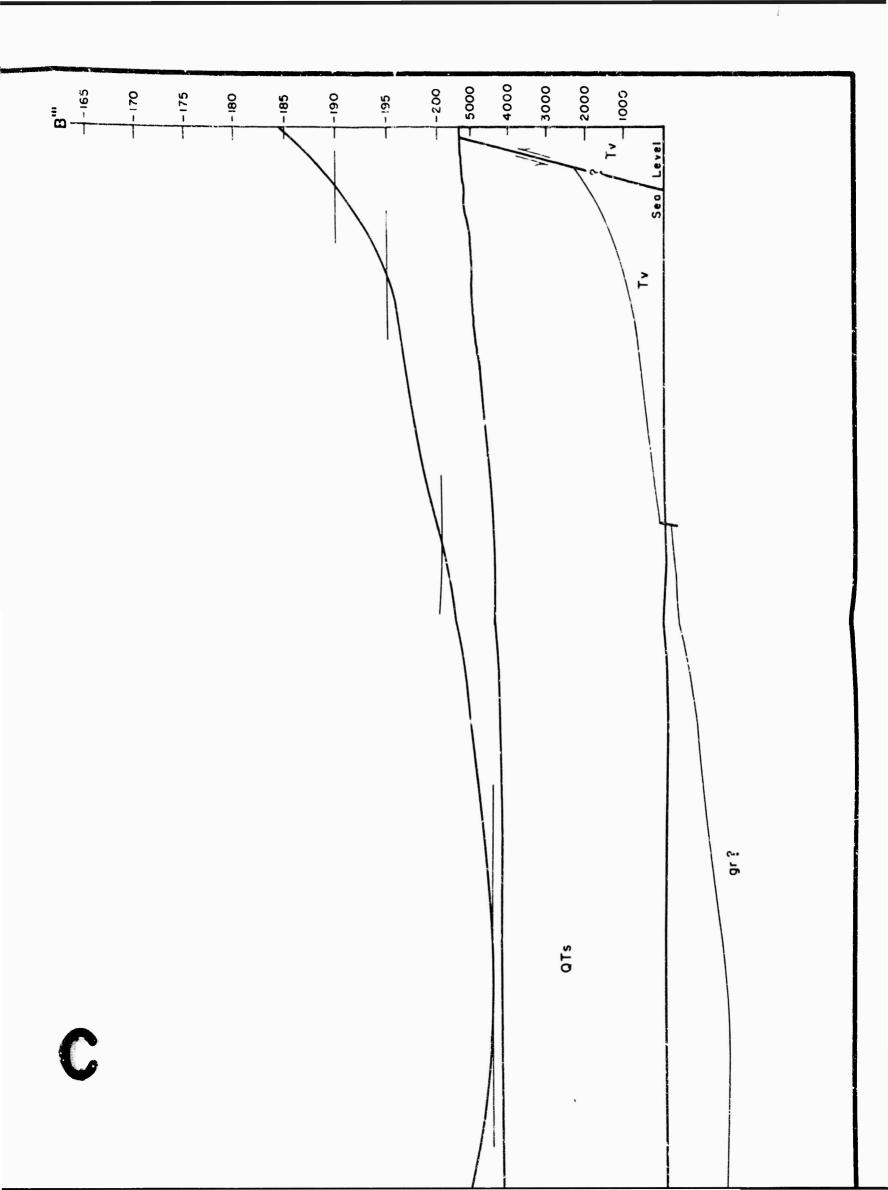


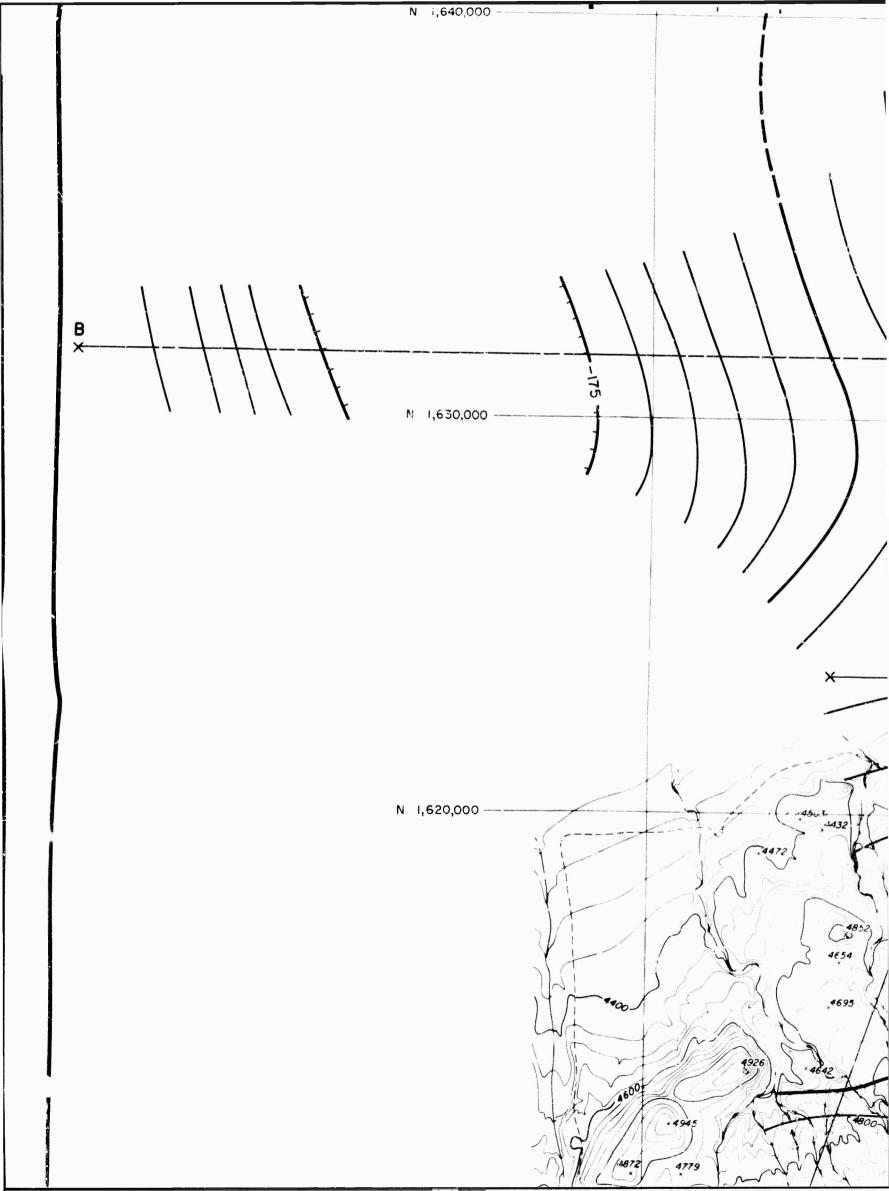


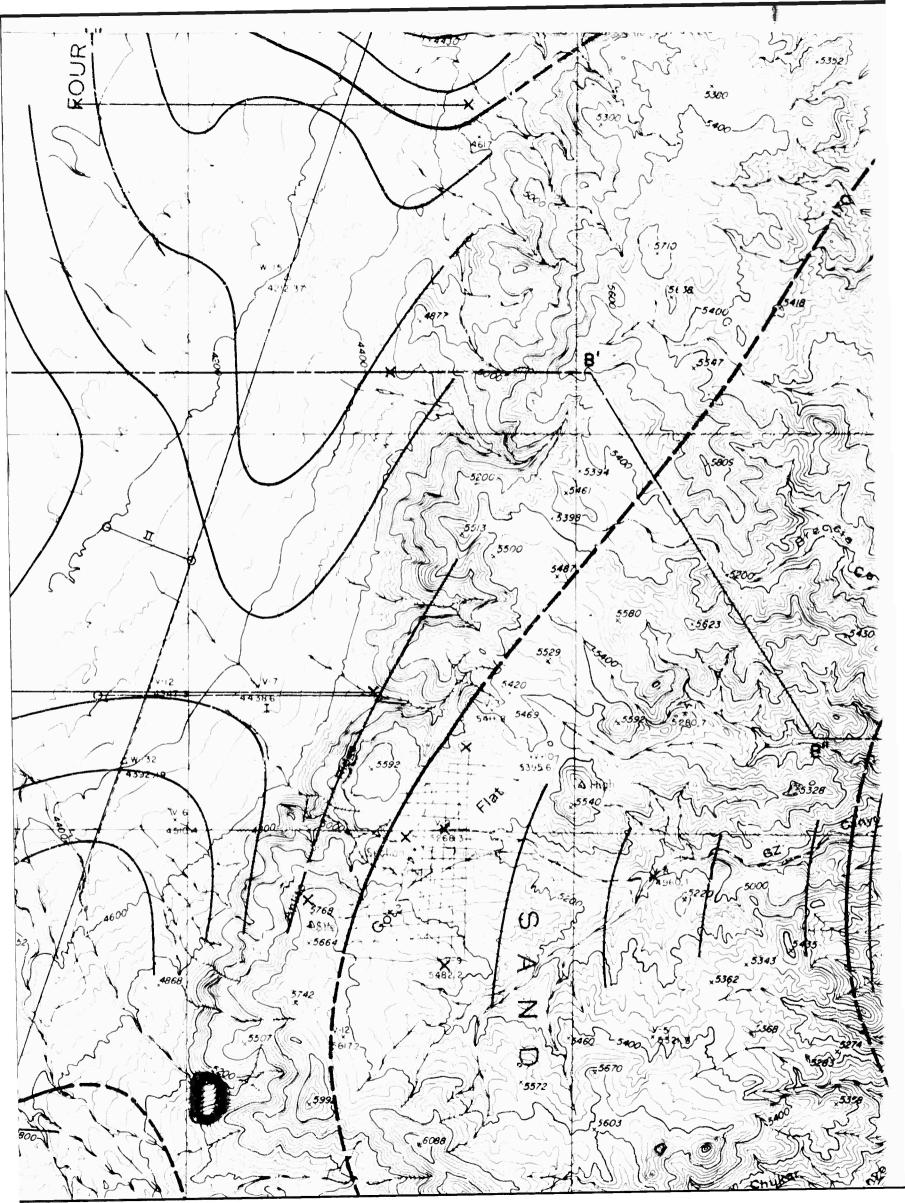


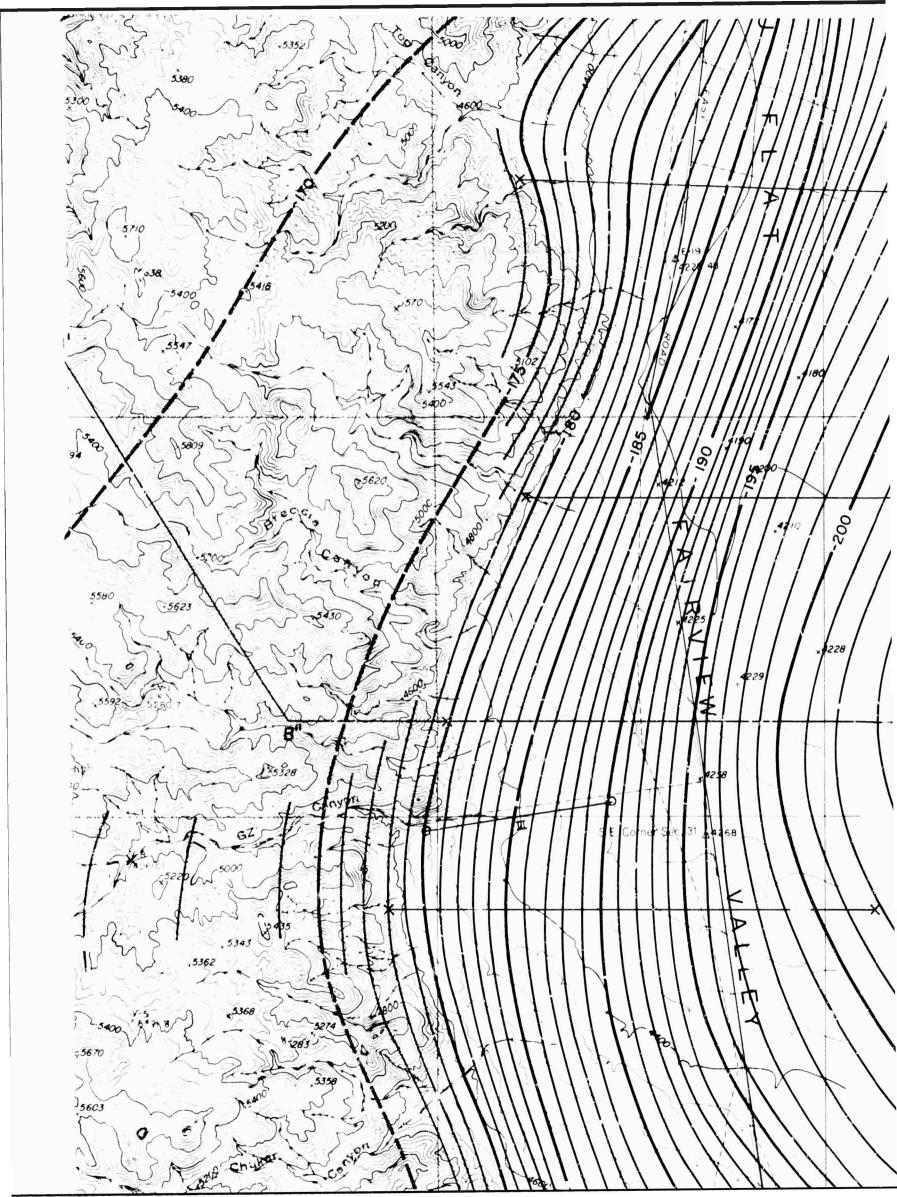


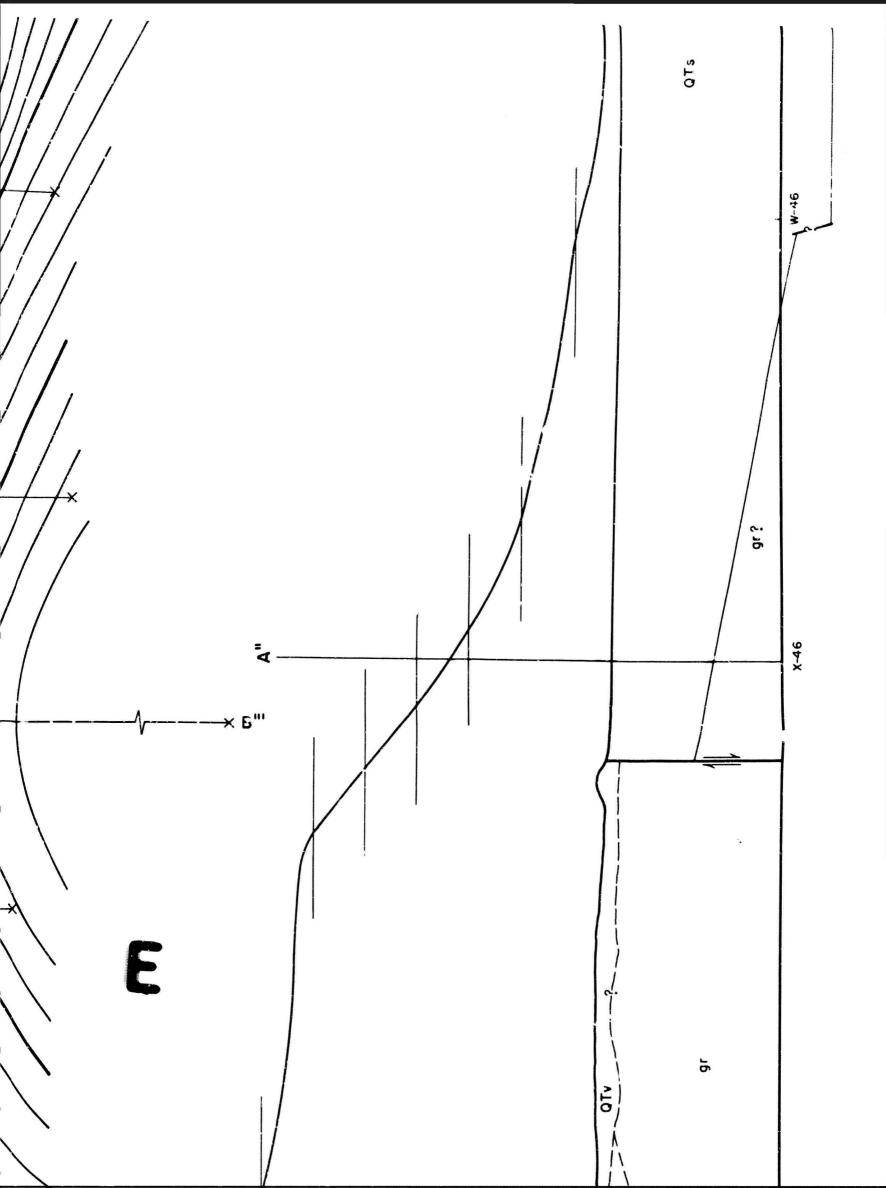


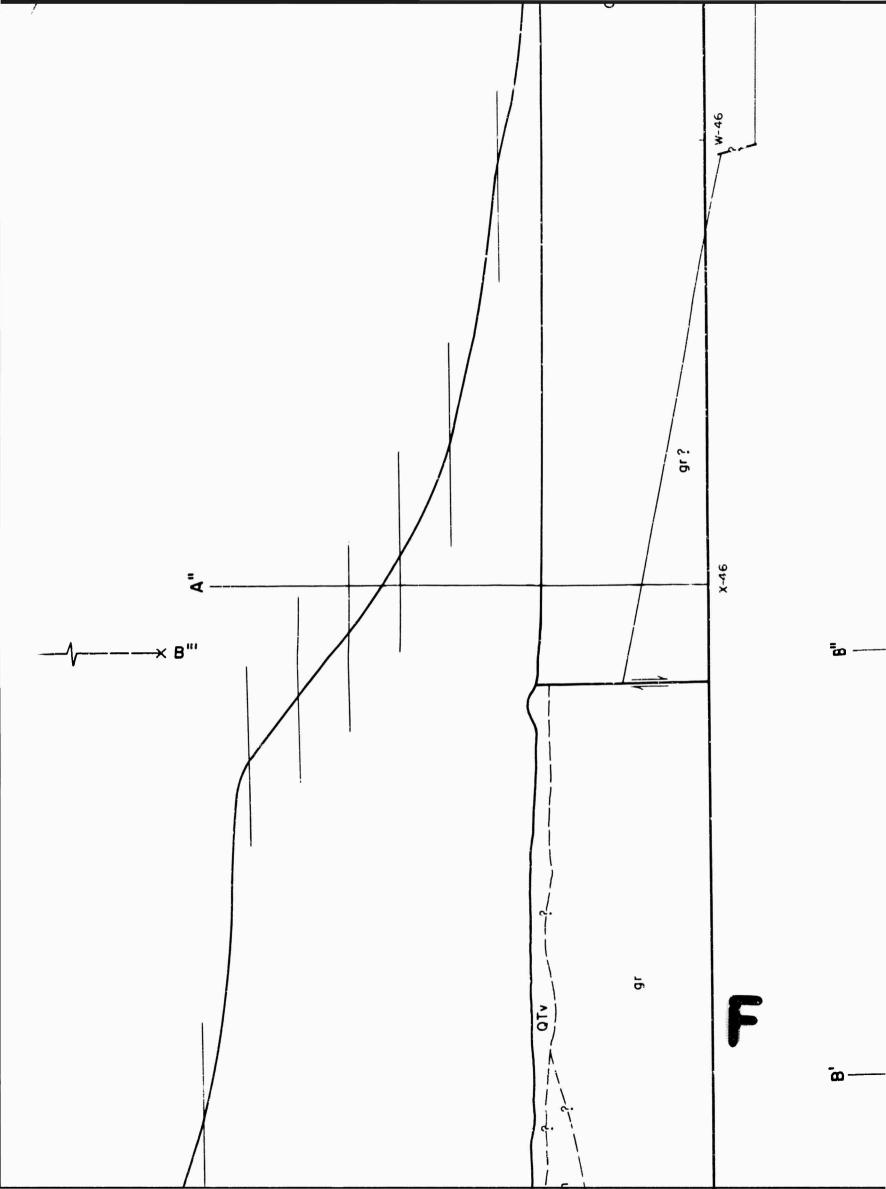


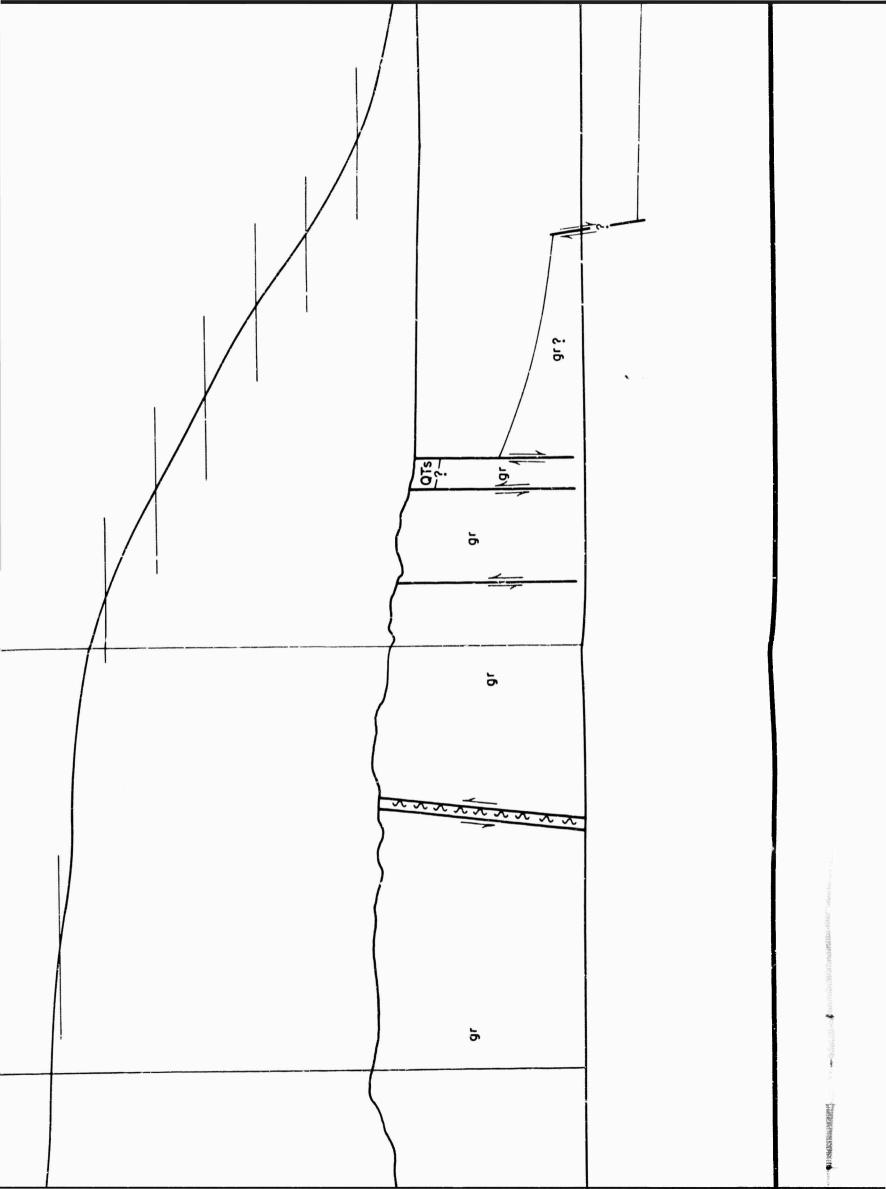


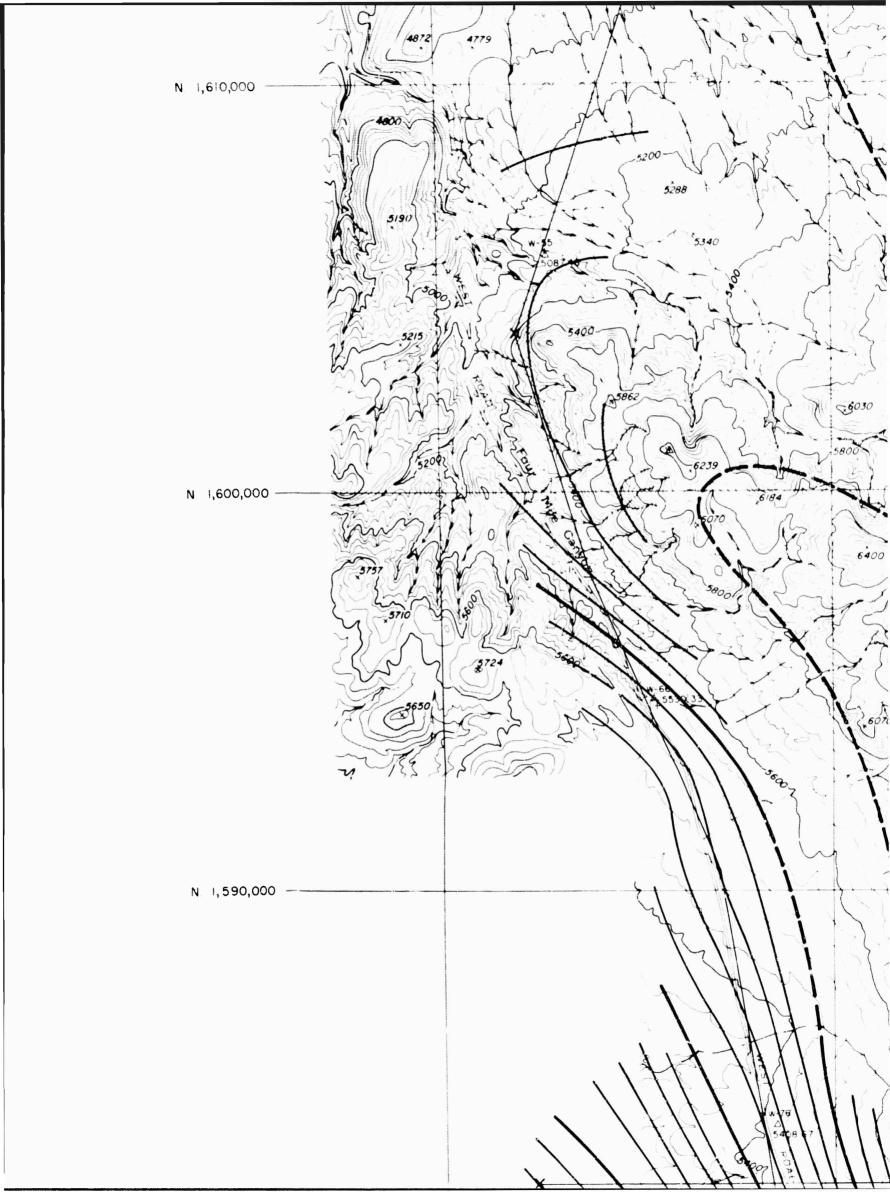


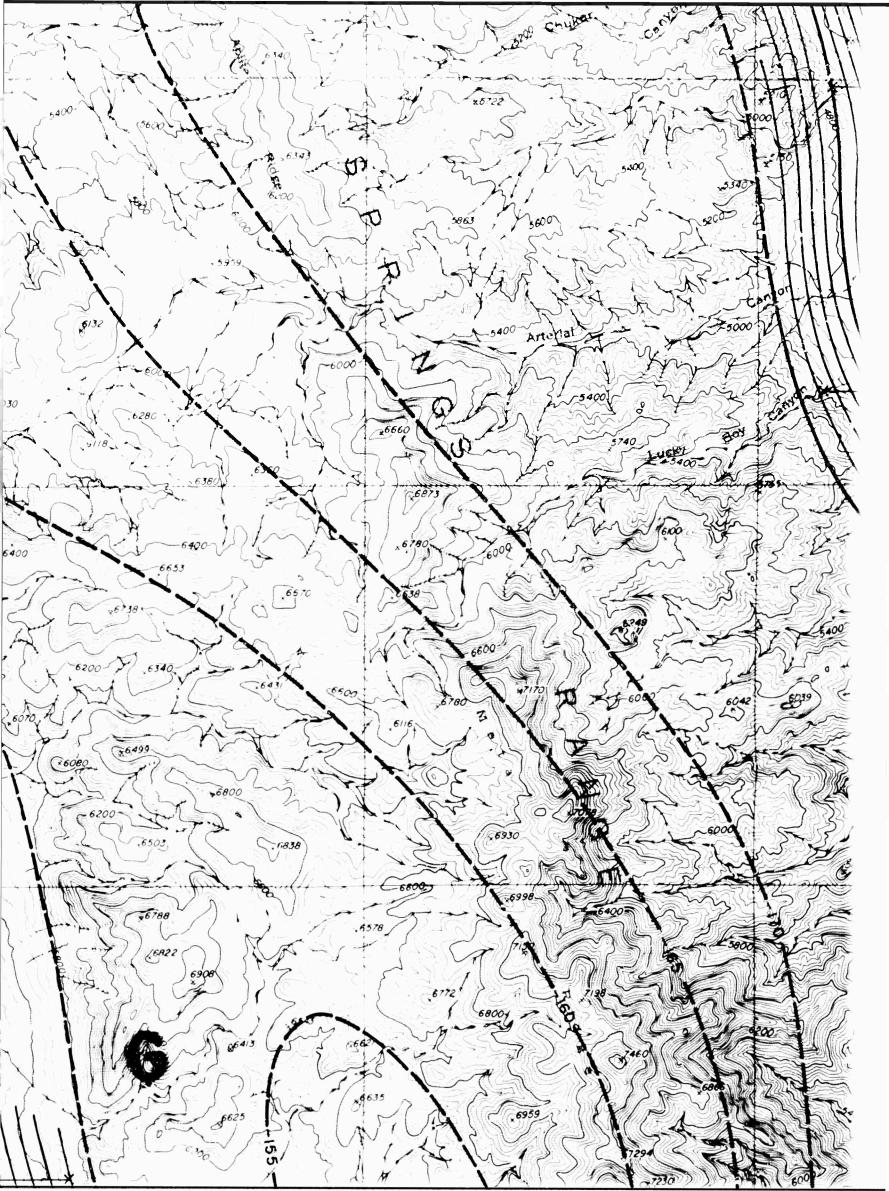


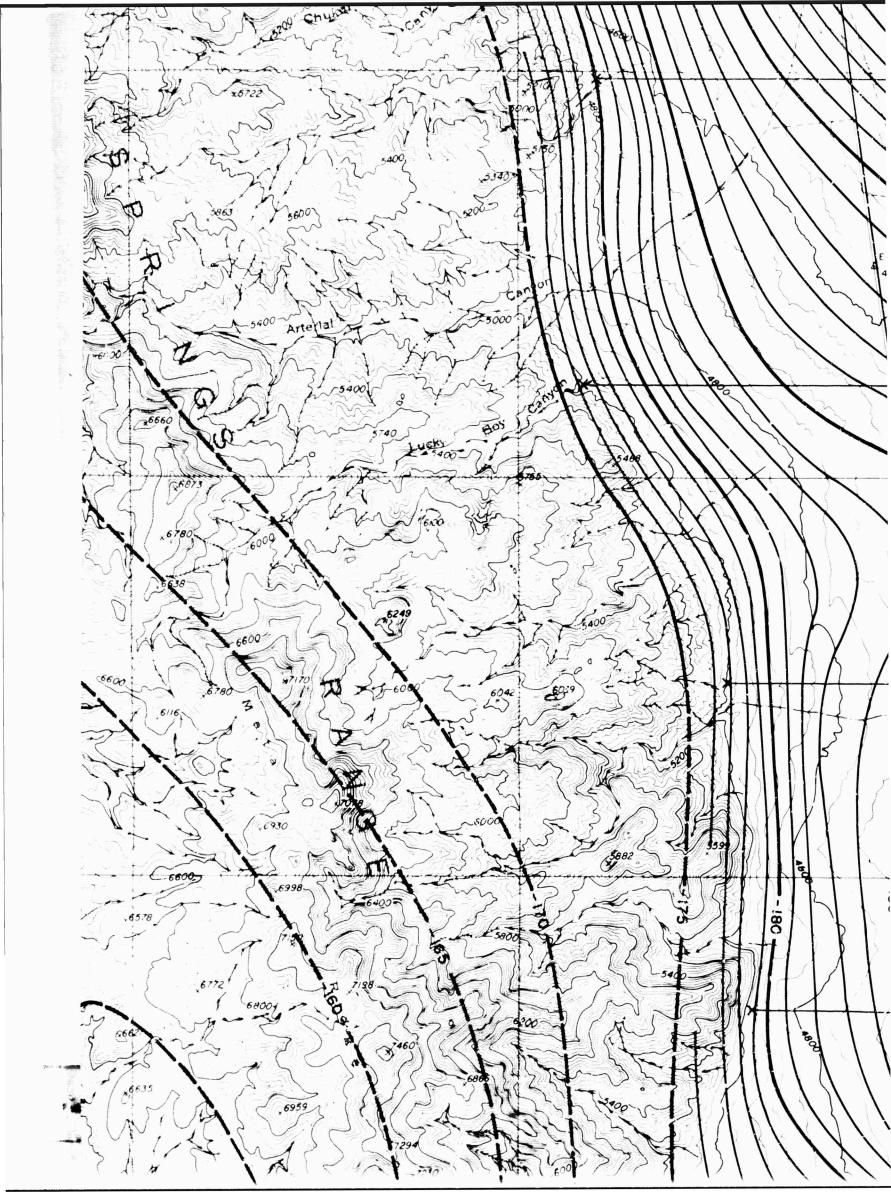


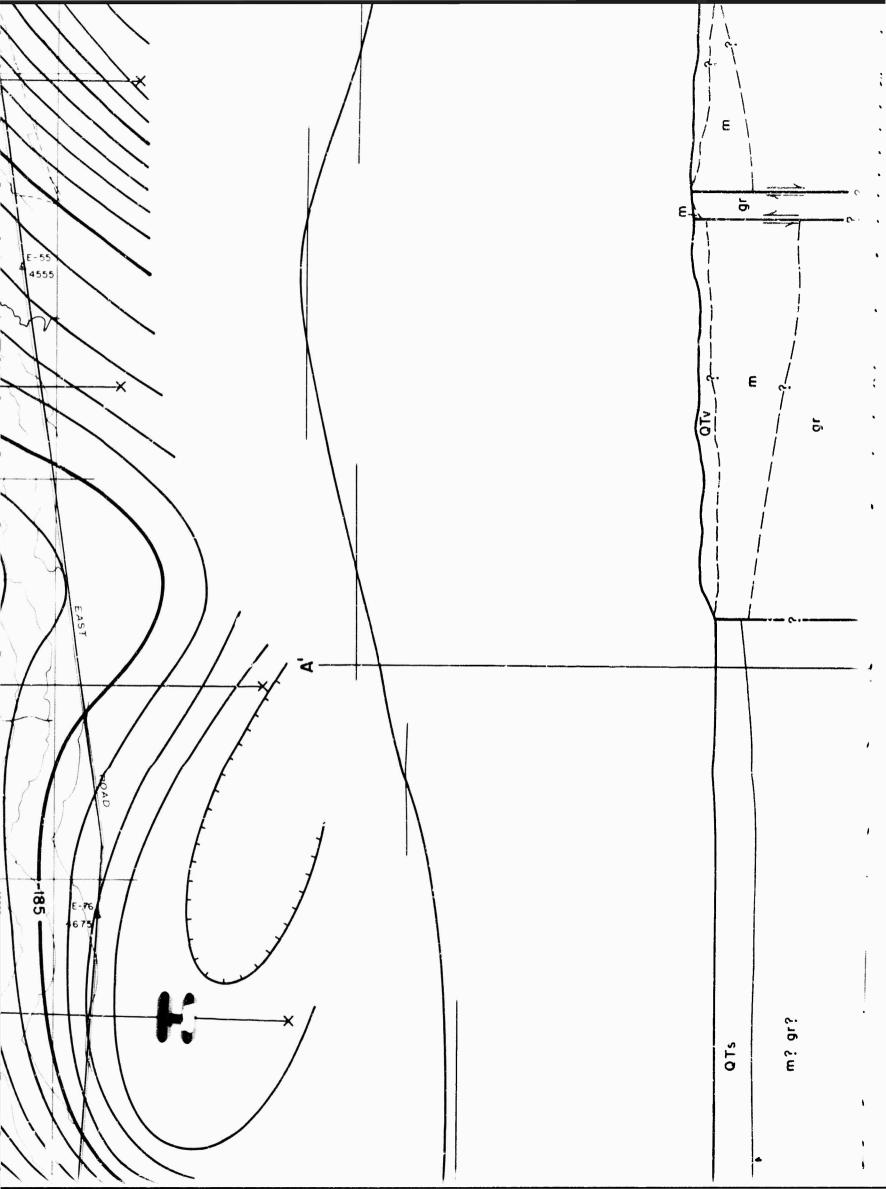


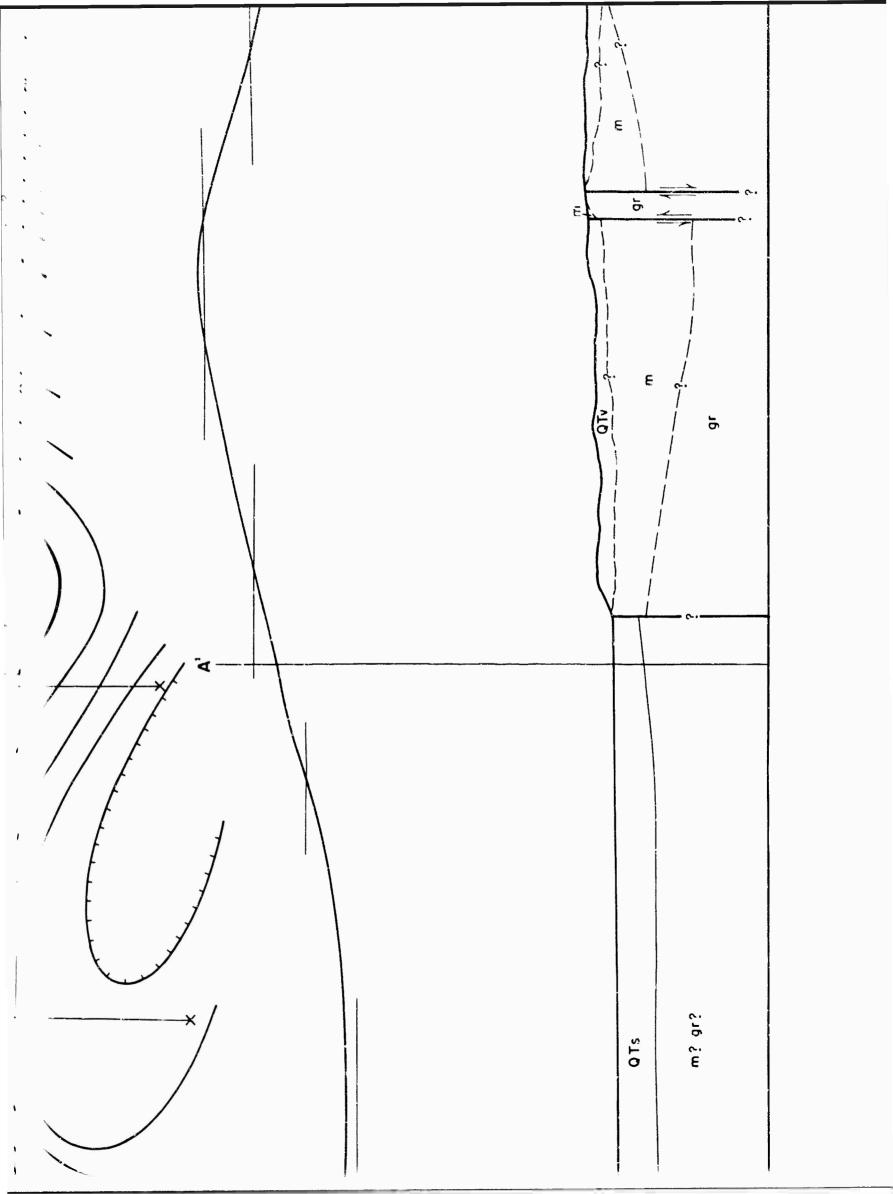


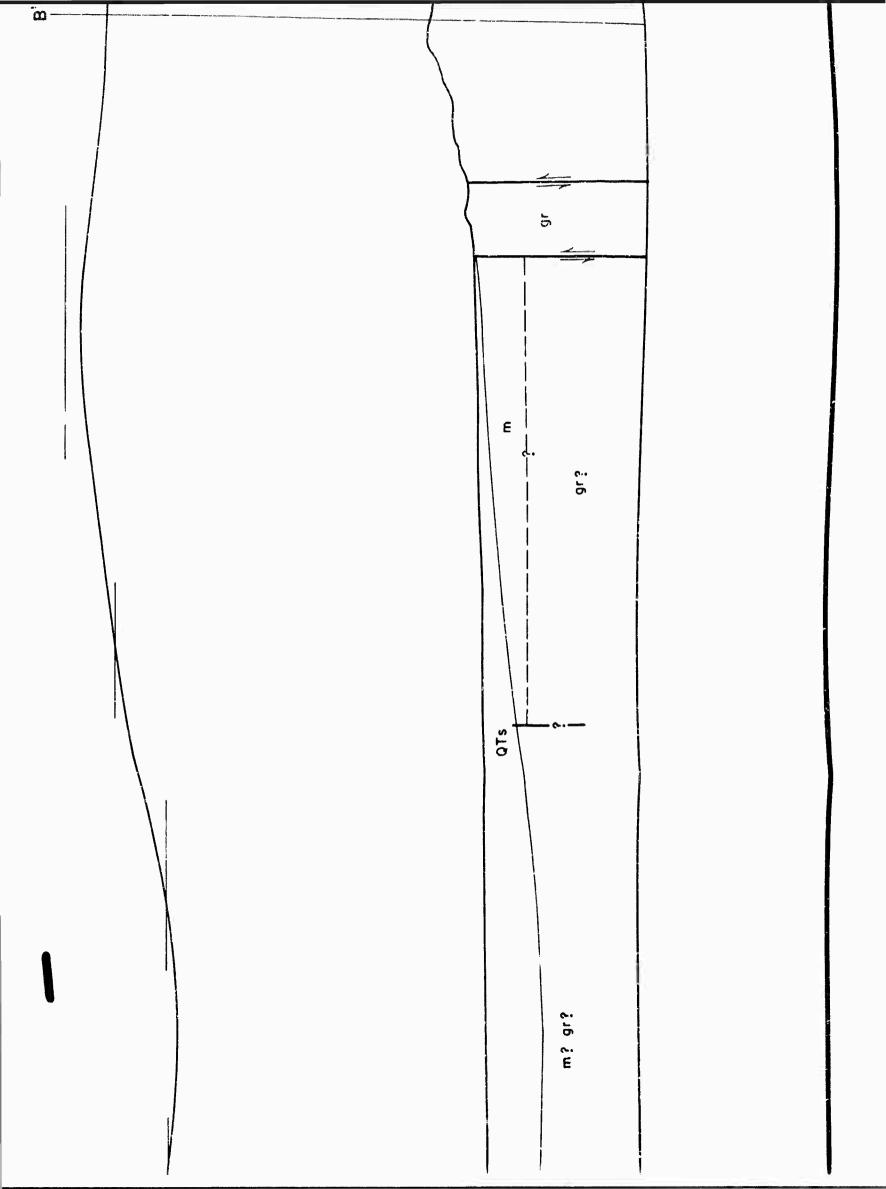


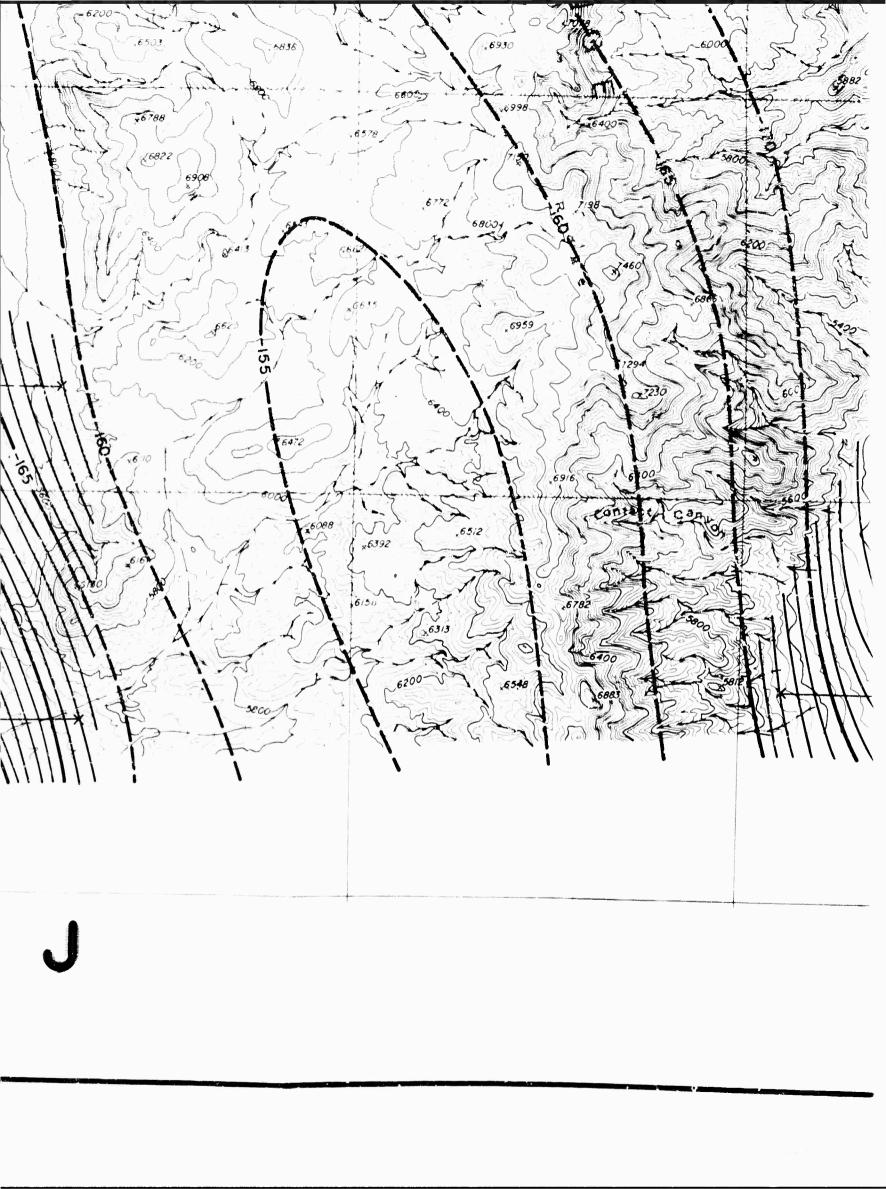


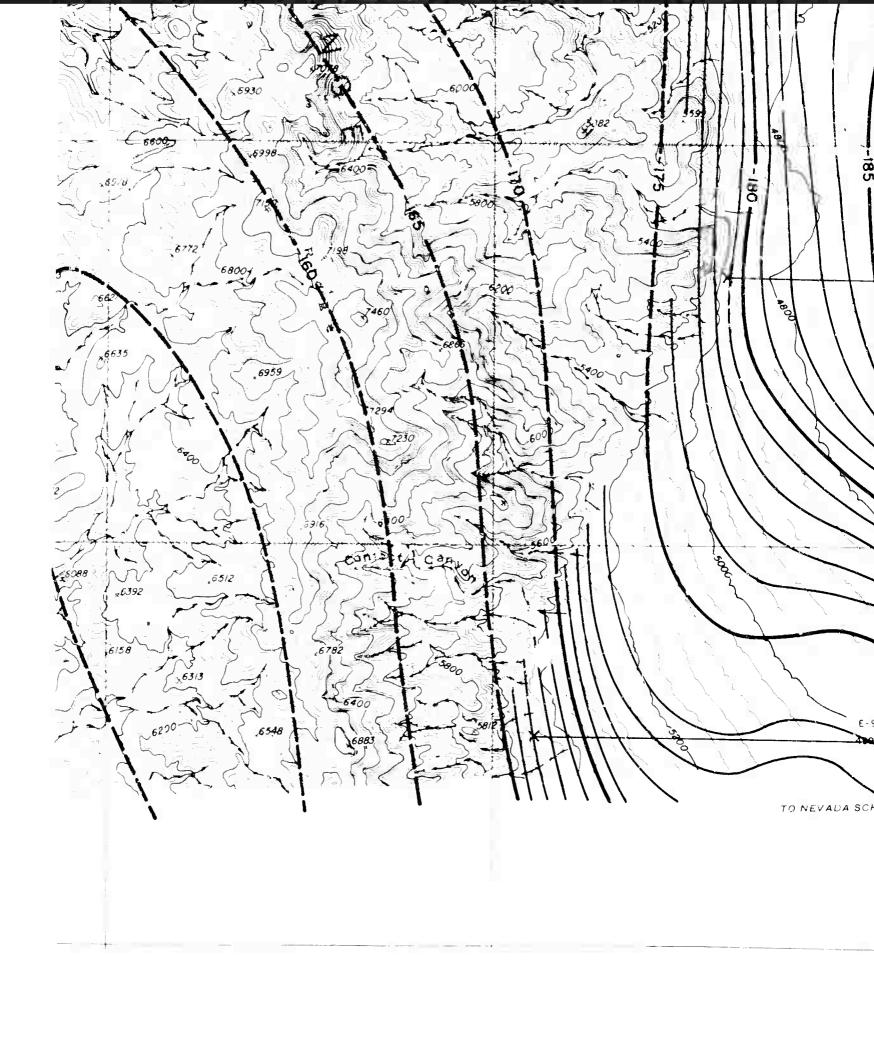


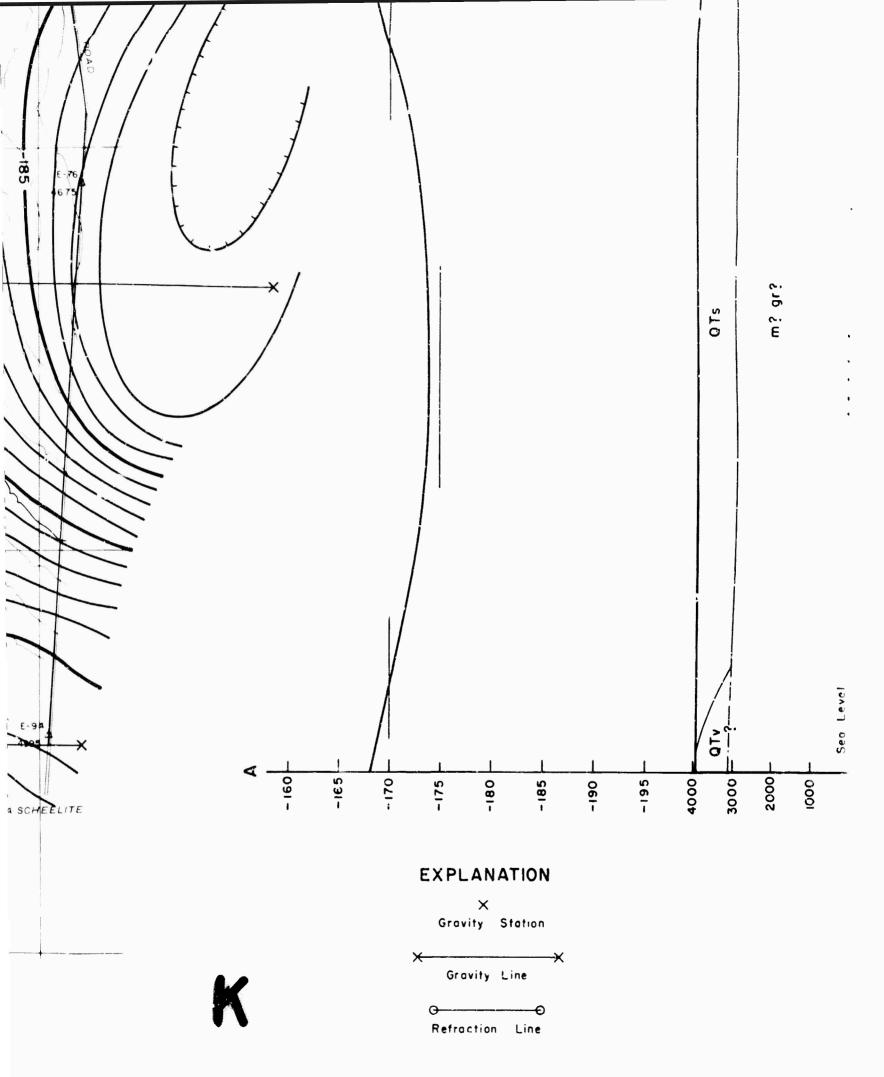




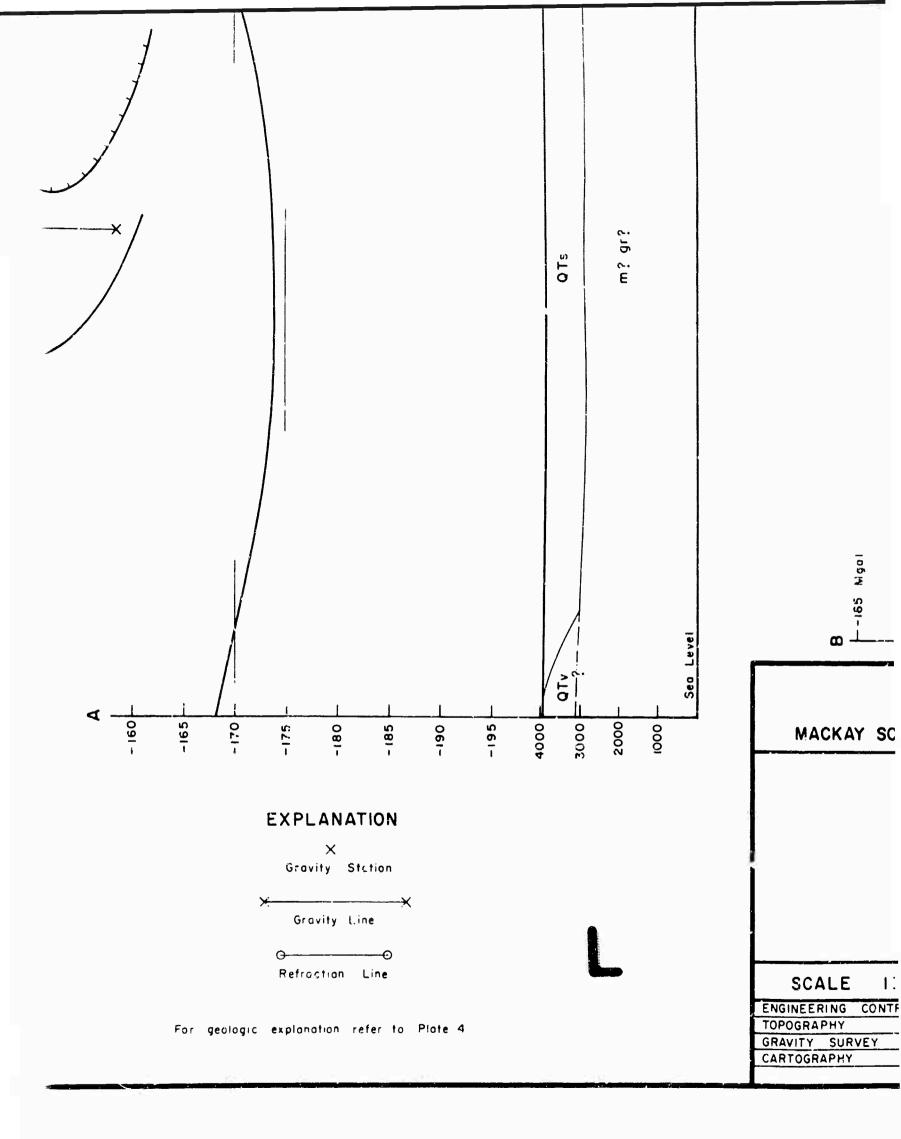


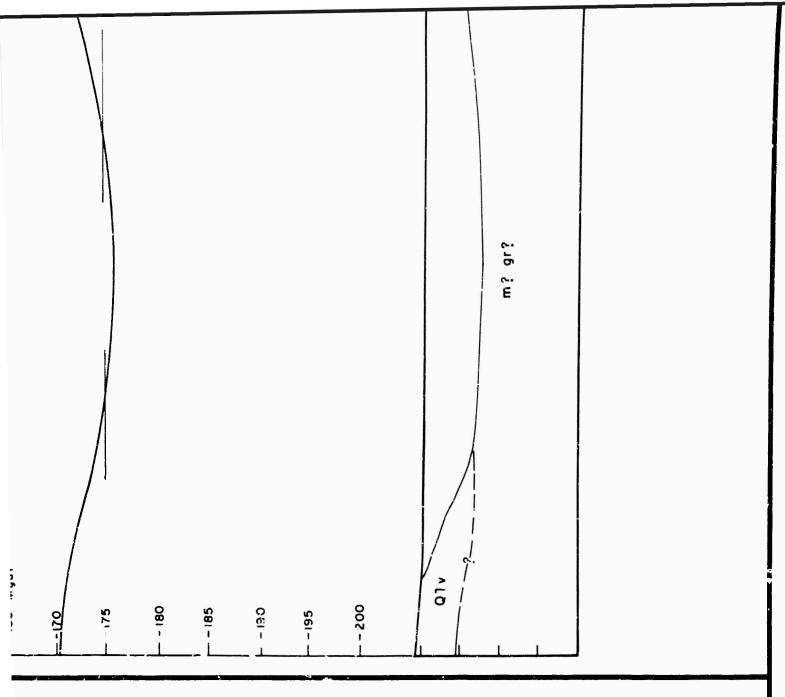






For geologic explanation refer to Plate 4





NEVADA BUREAU OF MINES

SCHOOL OF MINES

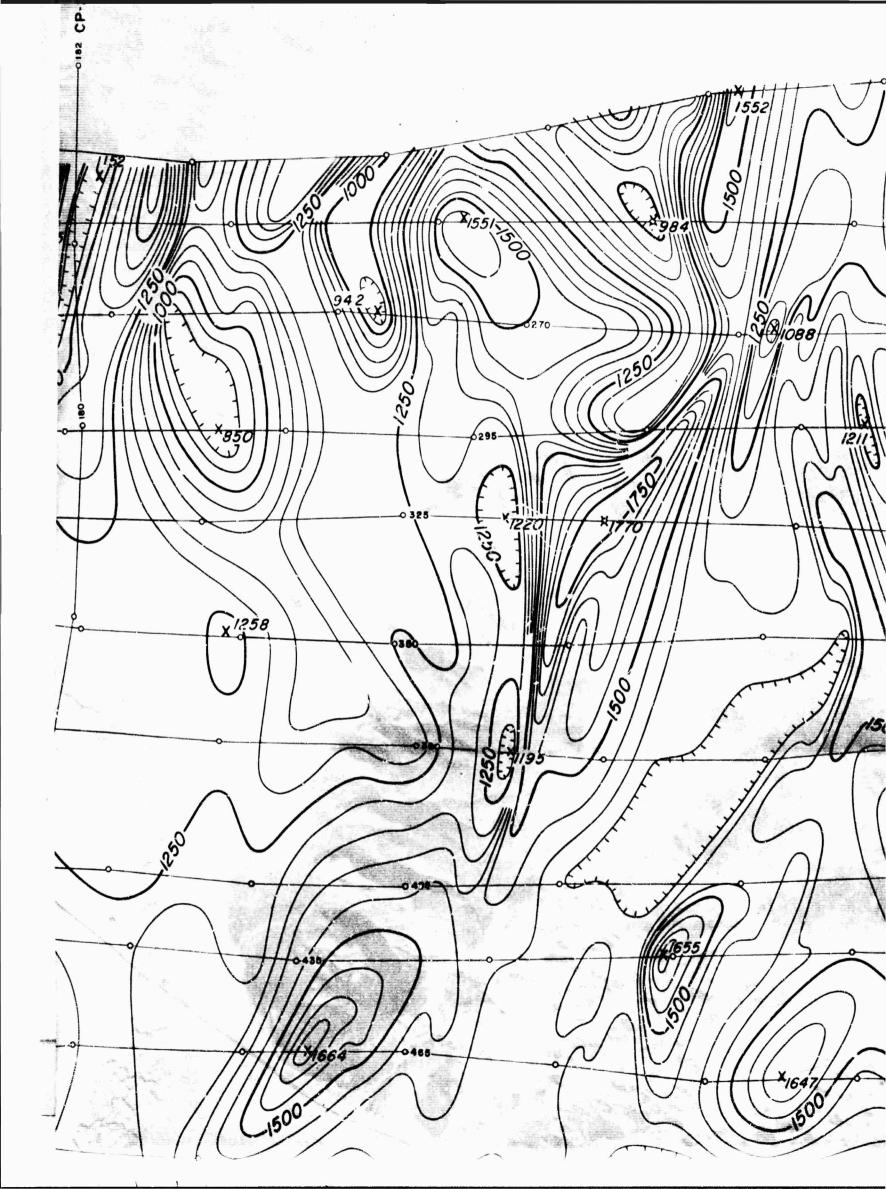
UNIVERSITY OF NEVADA

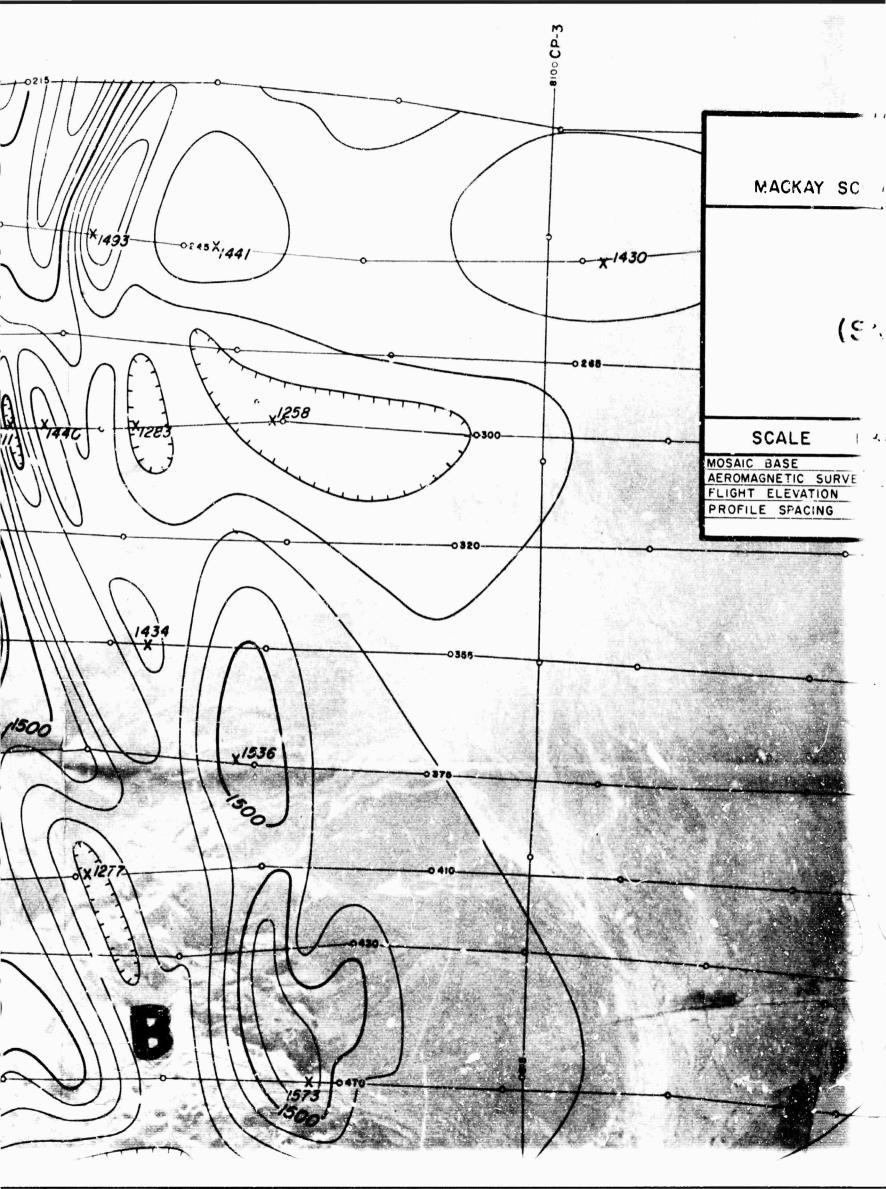
GRAVITY MAP AND PROFILES SAND SPRINGS RANGE AND VICINITY

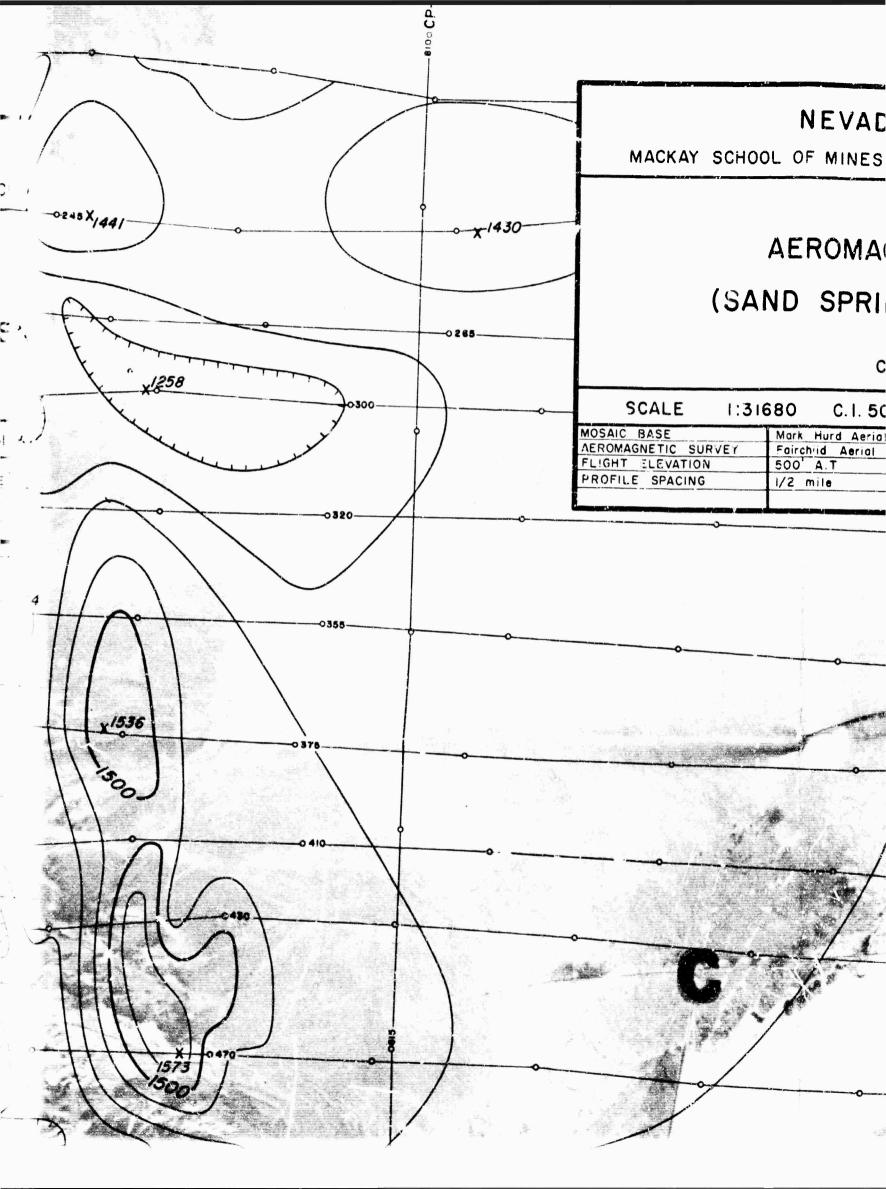
CHURCHILL COUNTY, NEVADA

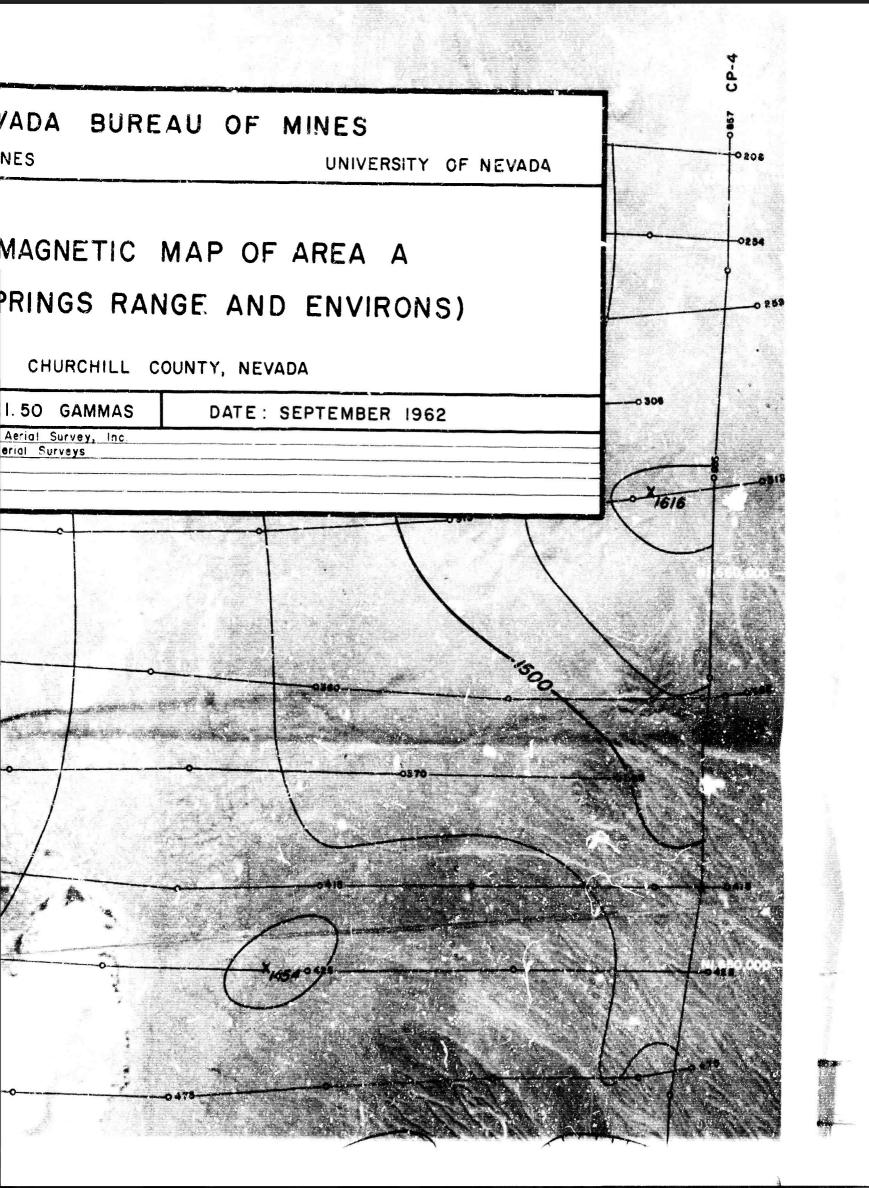
1: 31,68	BO C. I. I.O Mgal	DATE: SEPTEMBER	1962
ONTROL	Sprout Engineers, Inc.		
	Mark Hurd Aerial Surveys, Inc.		
Υ	NBM personnel: J. Gimlett, R.	Harton, J. Schilling	
	R. Wilson		

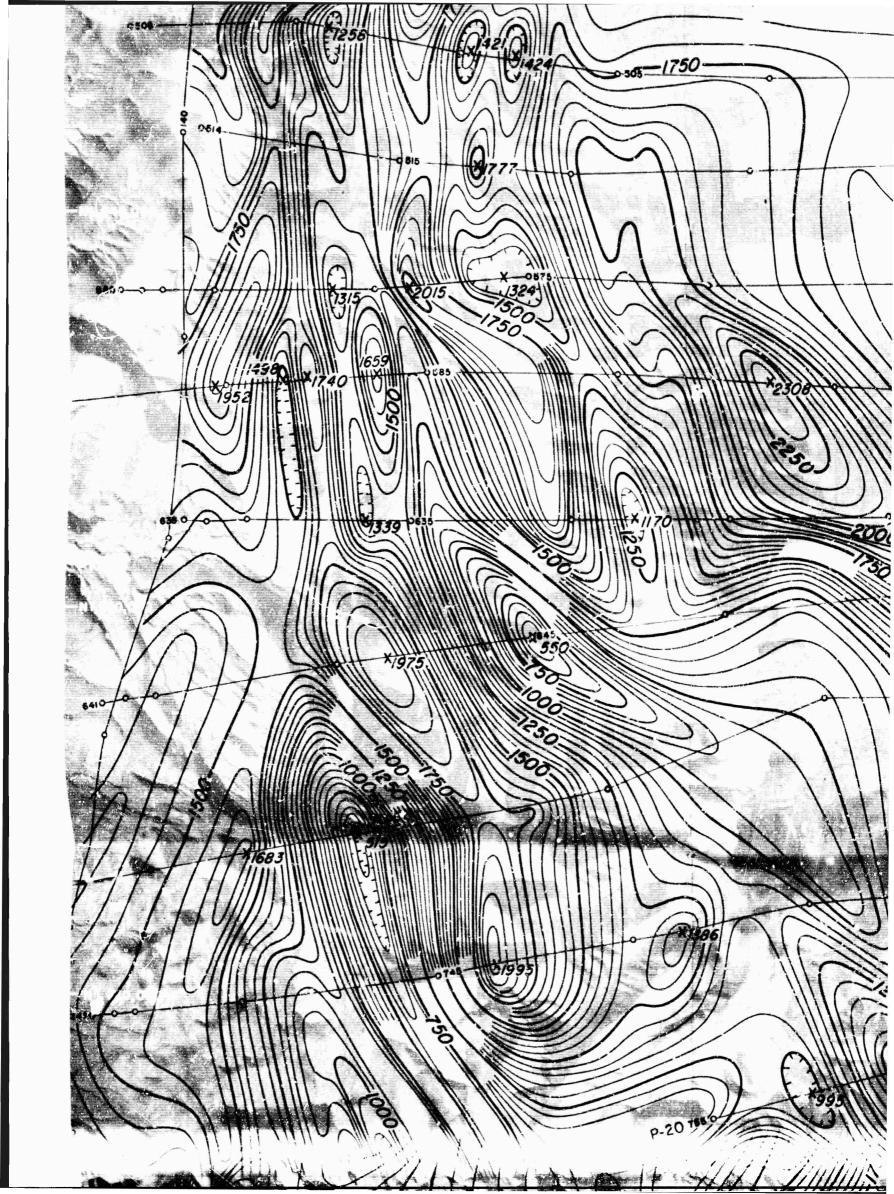


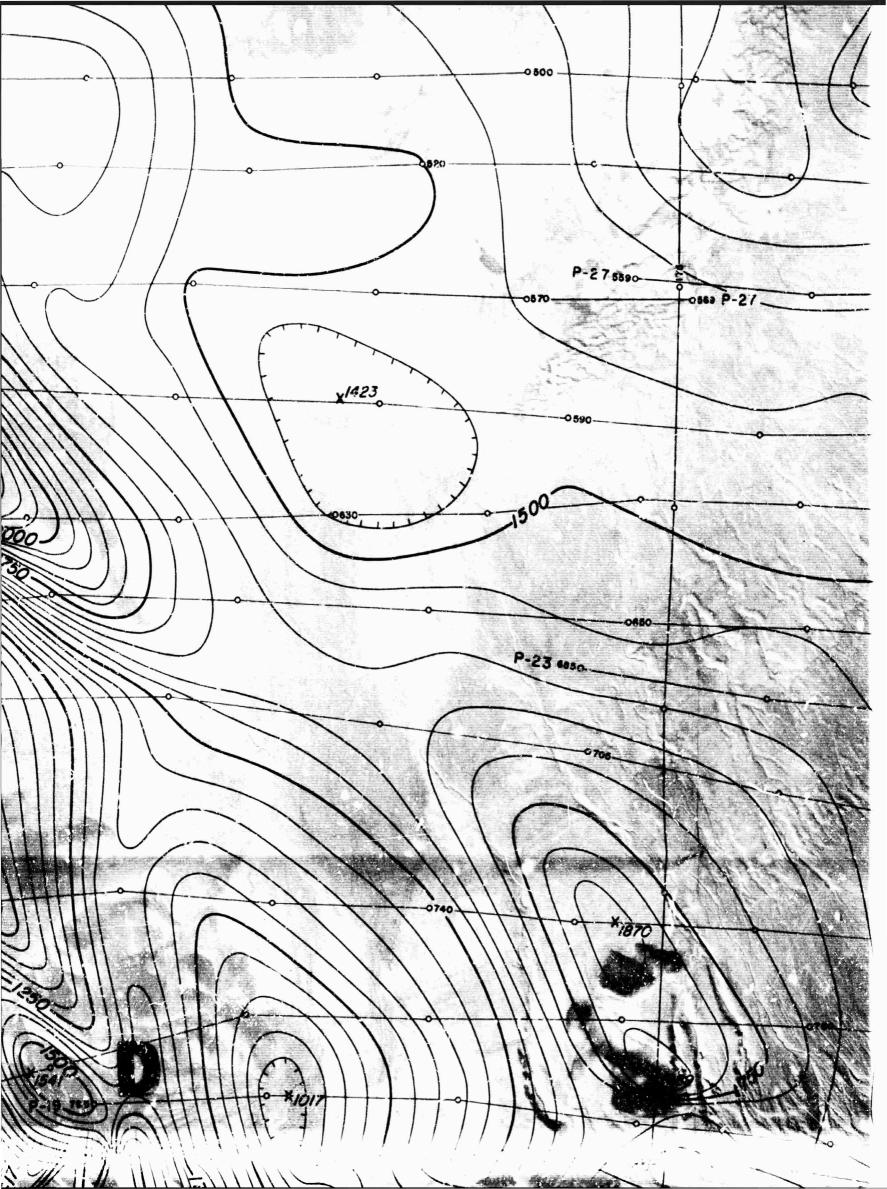








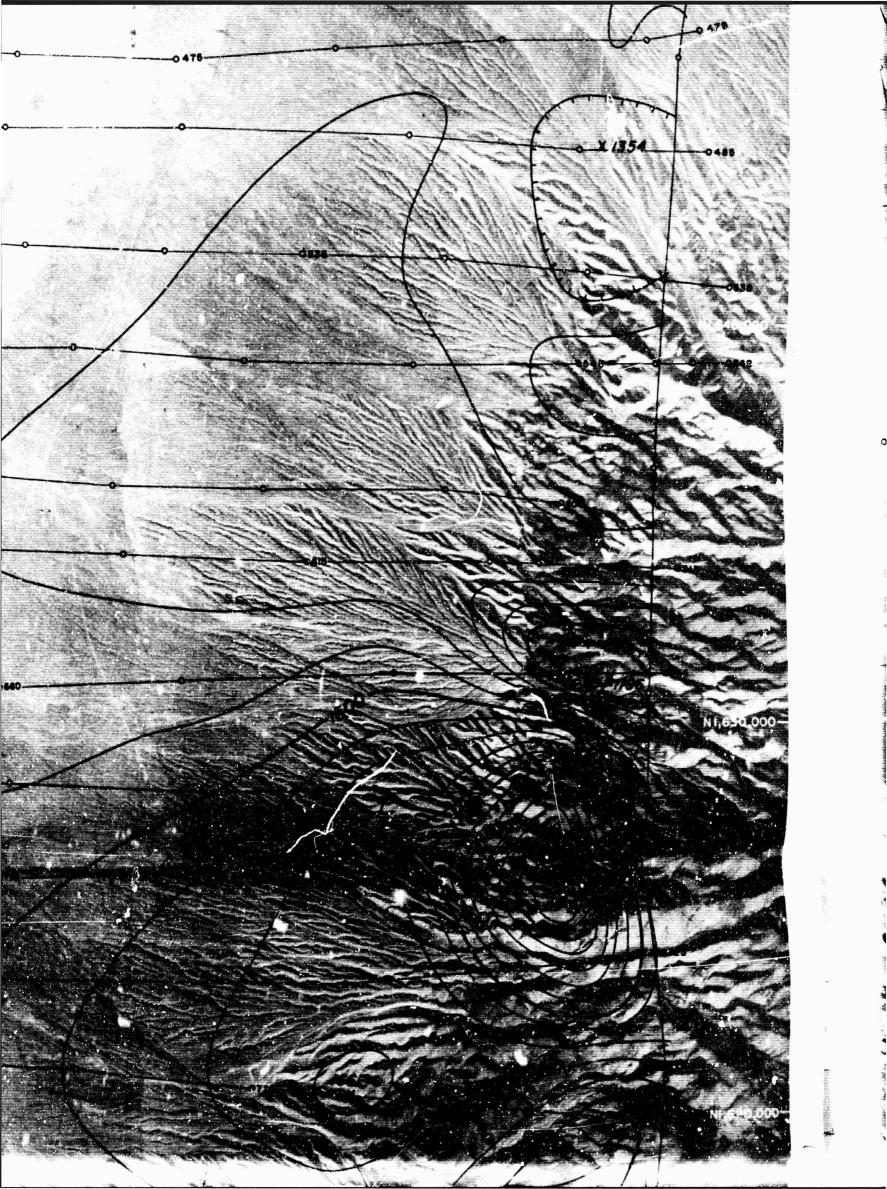


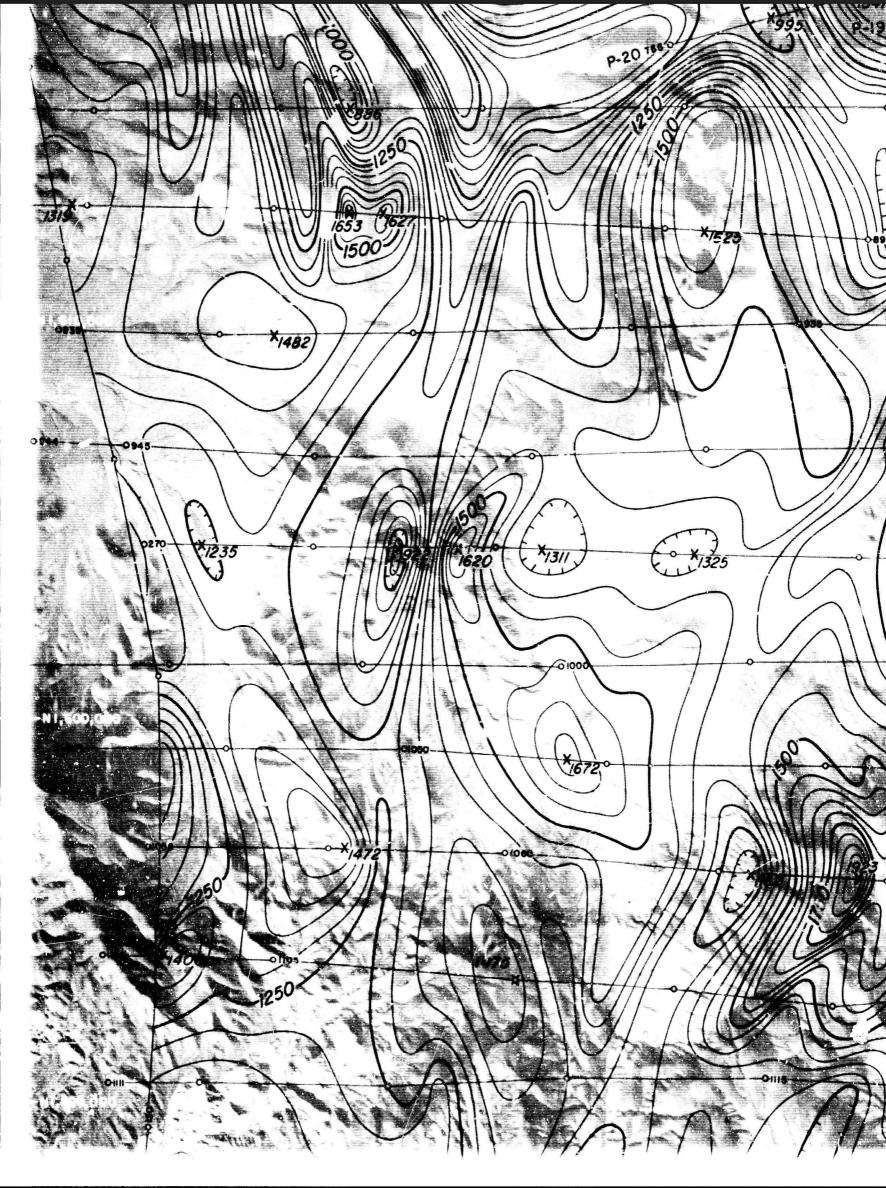


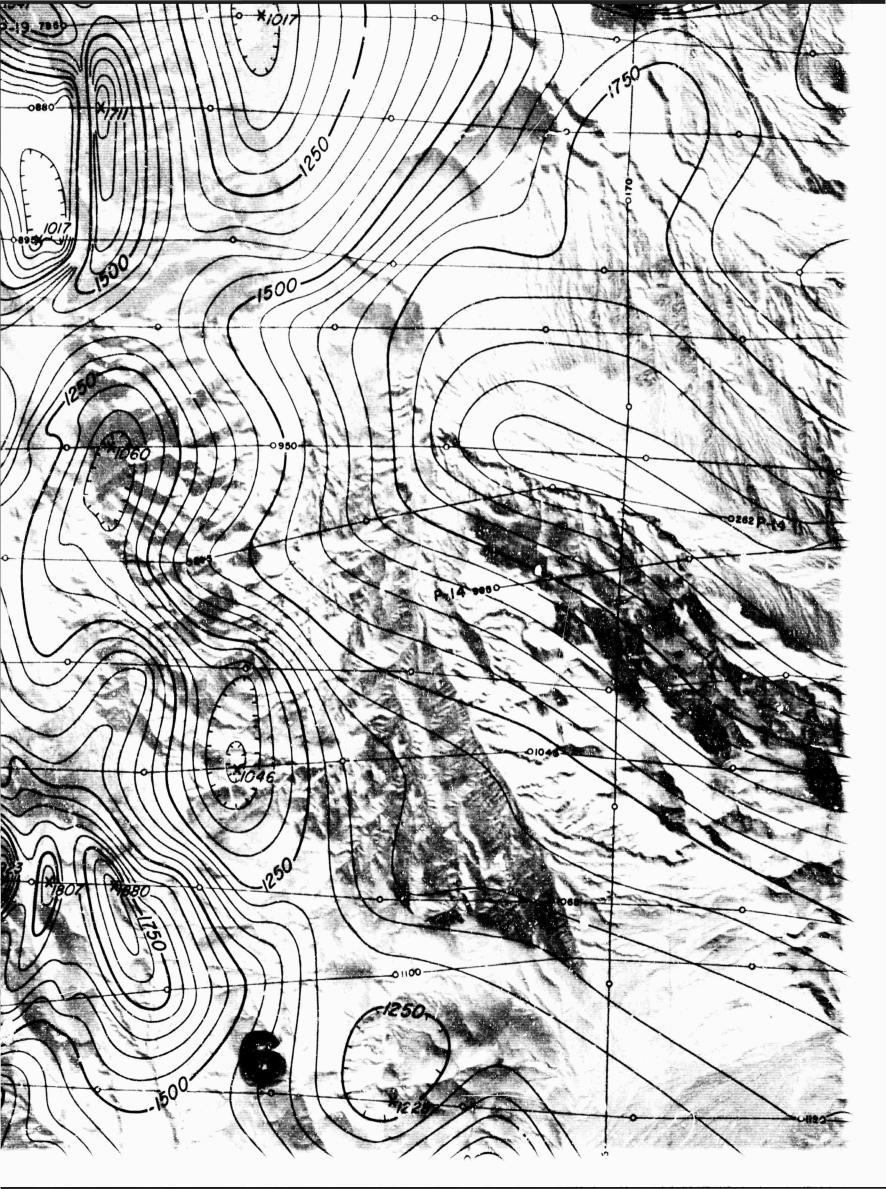


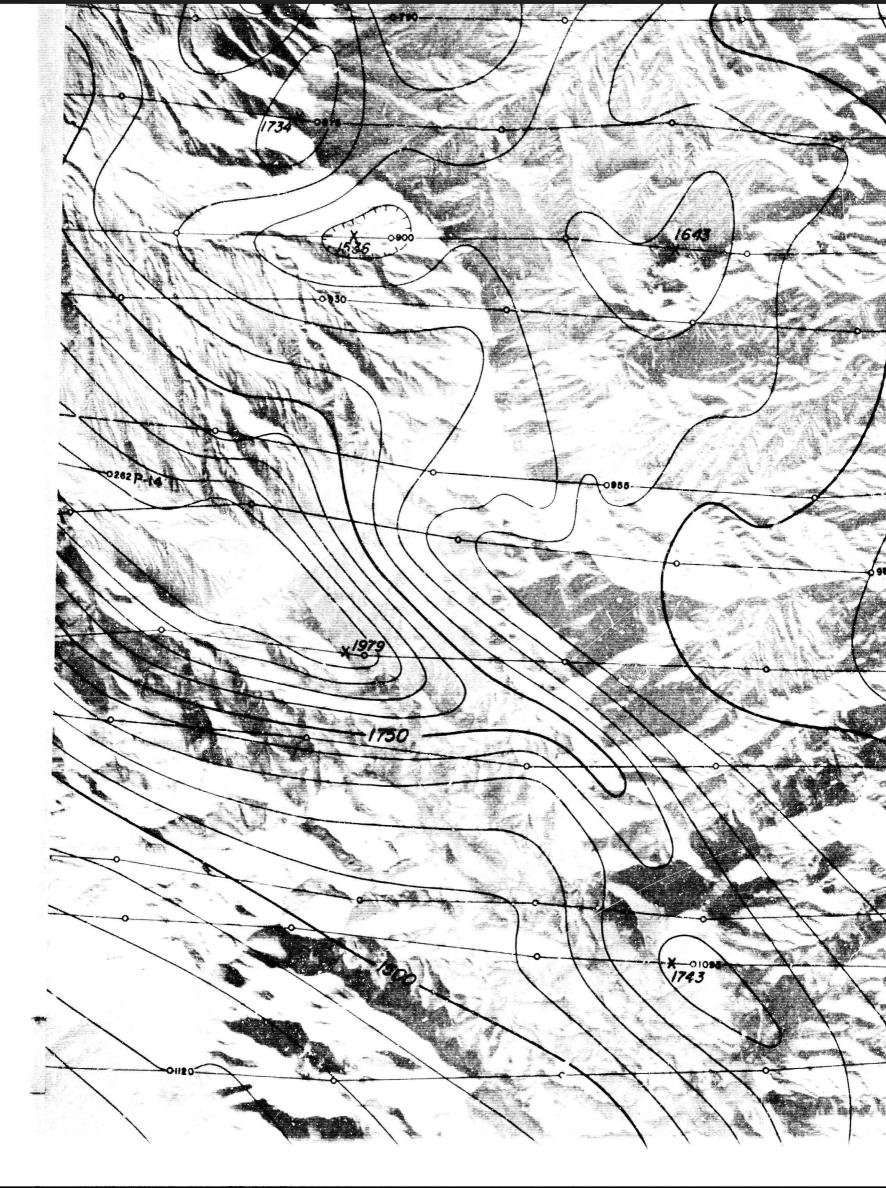


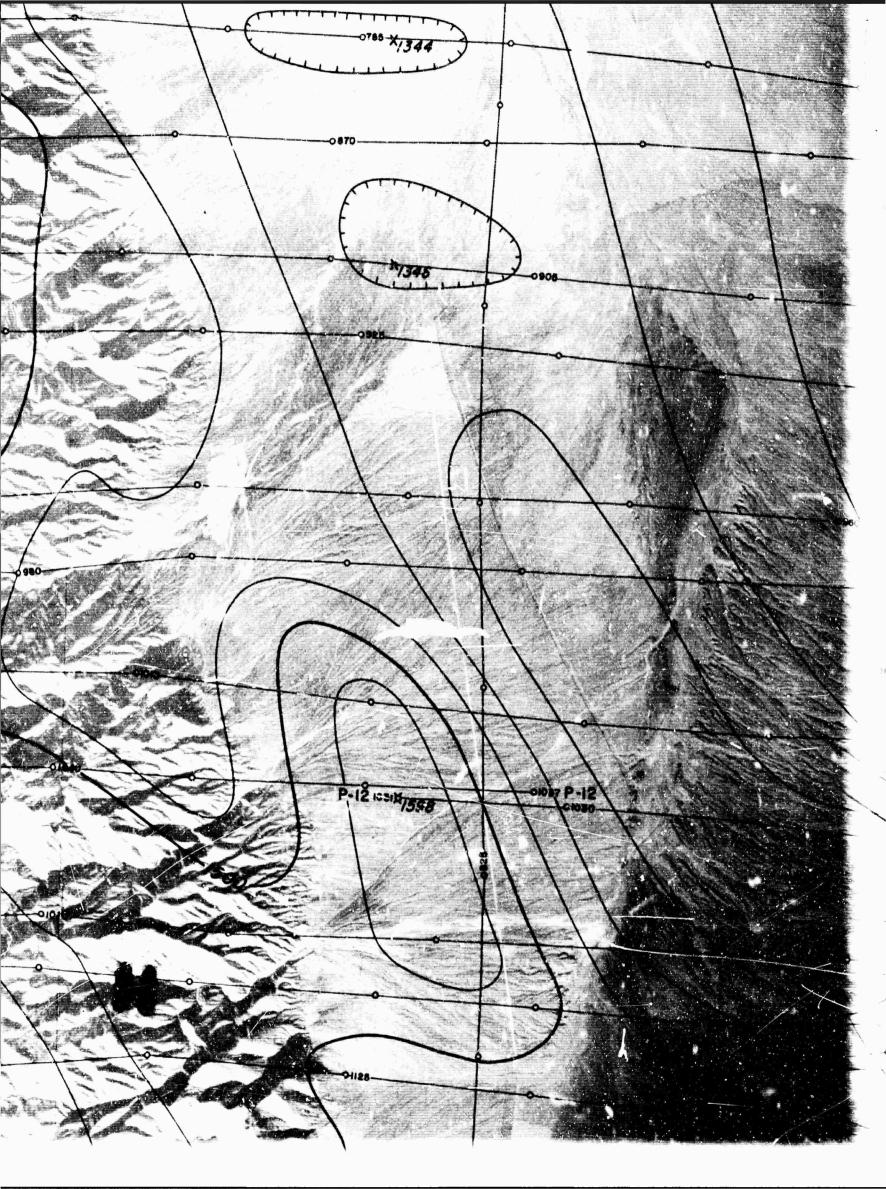


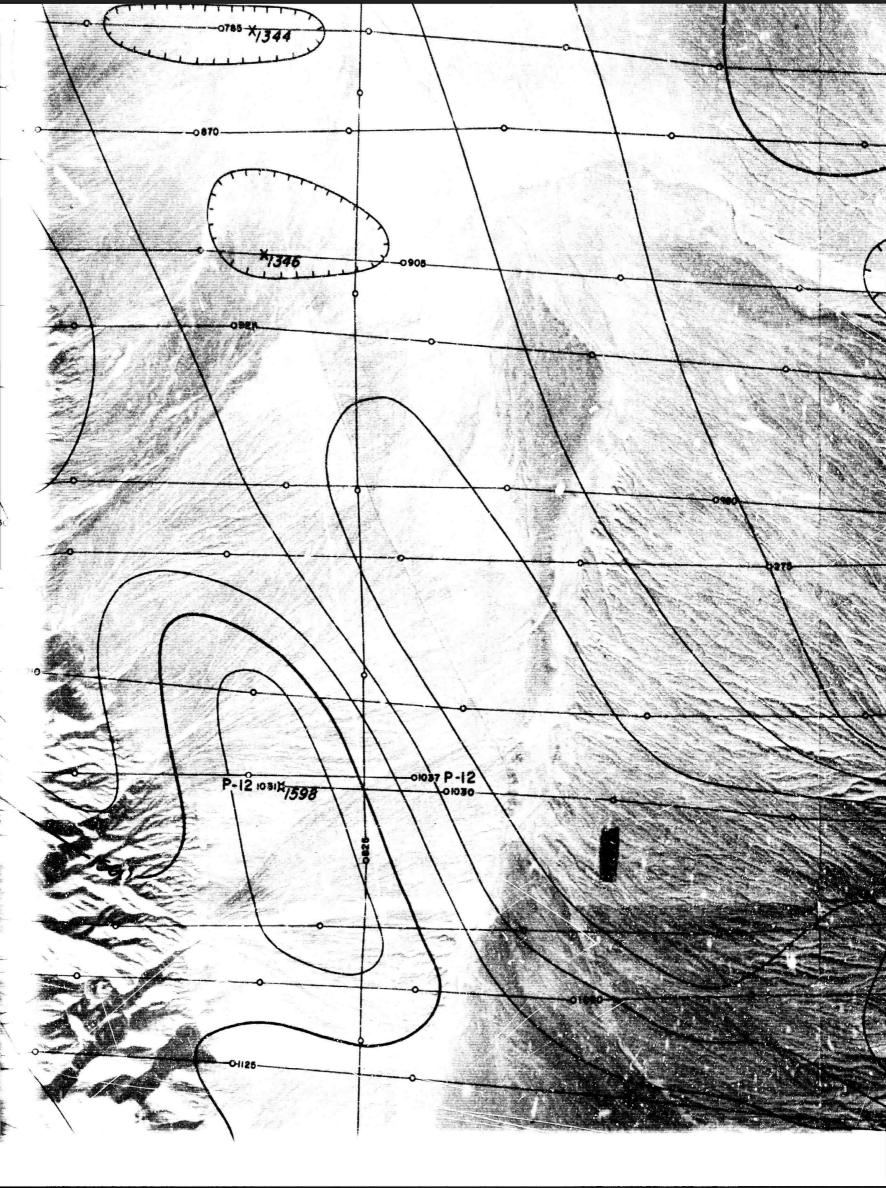


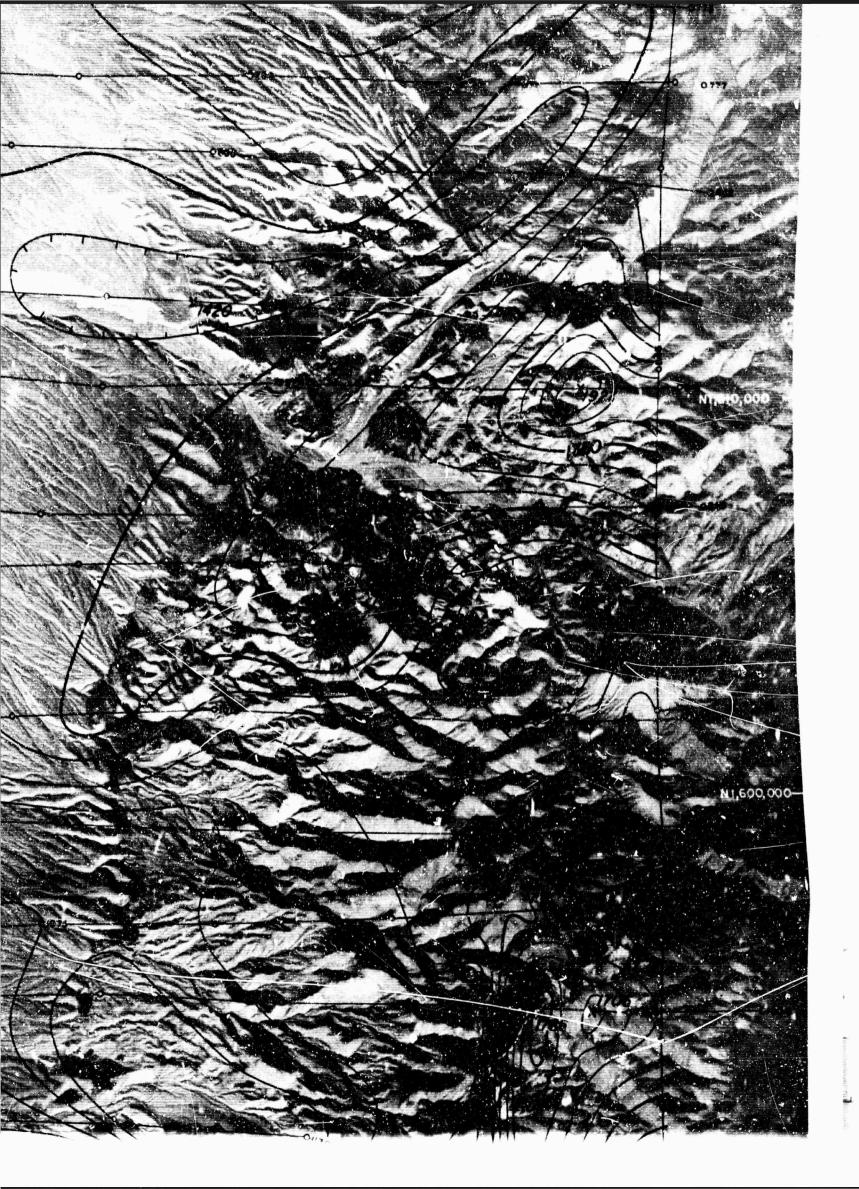


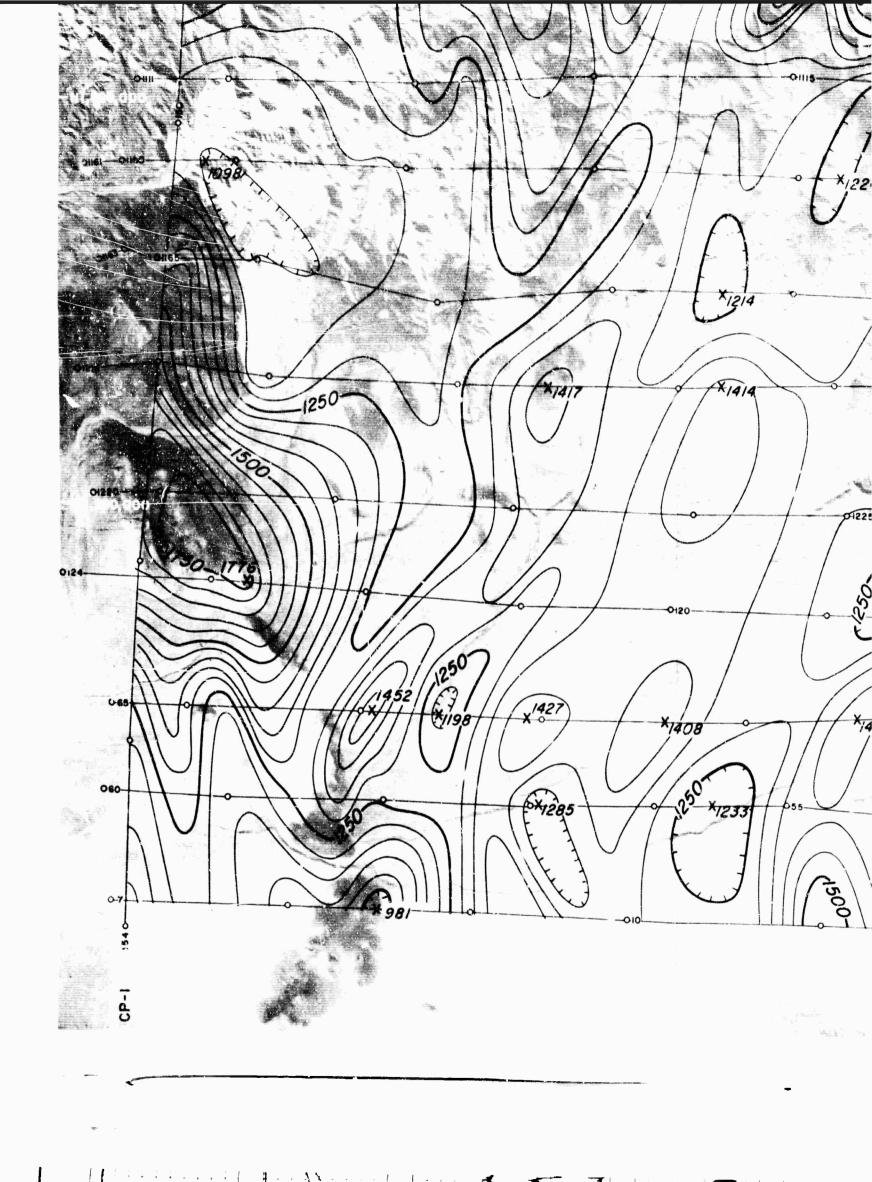


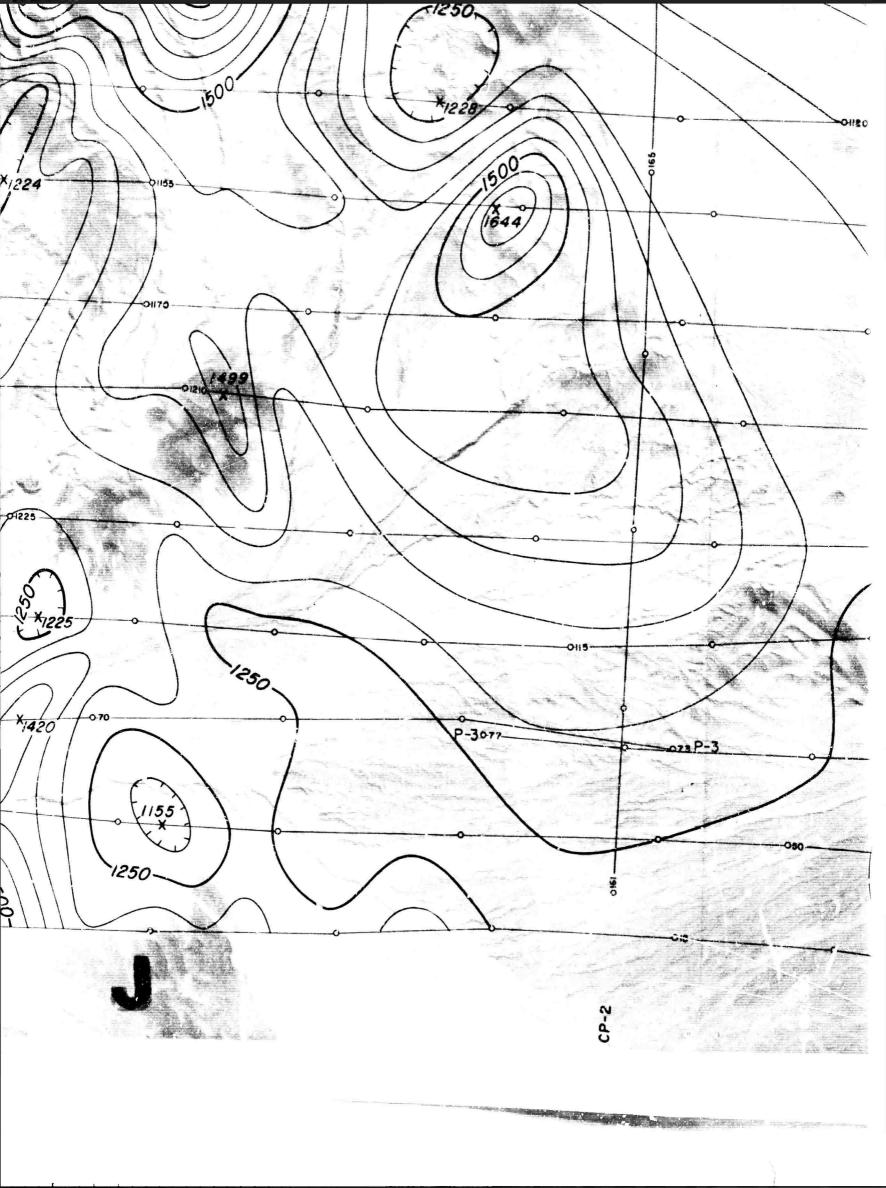


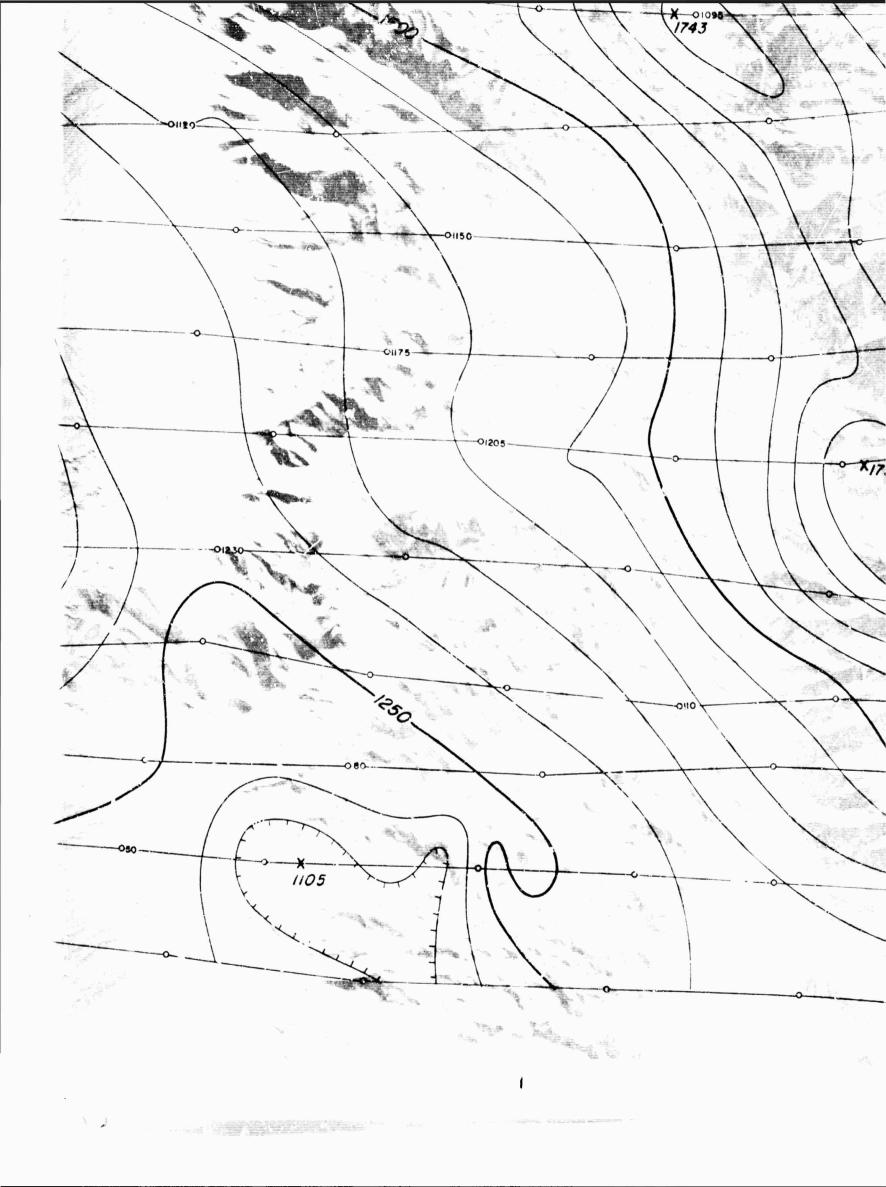


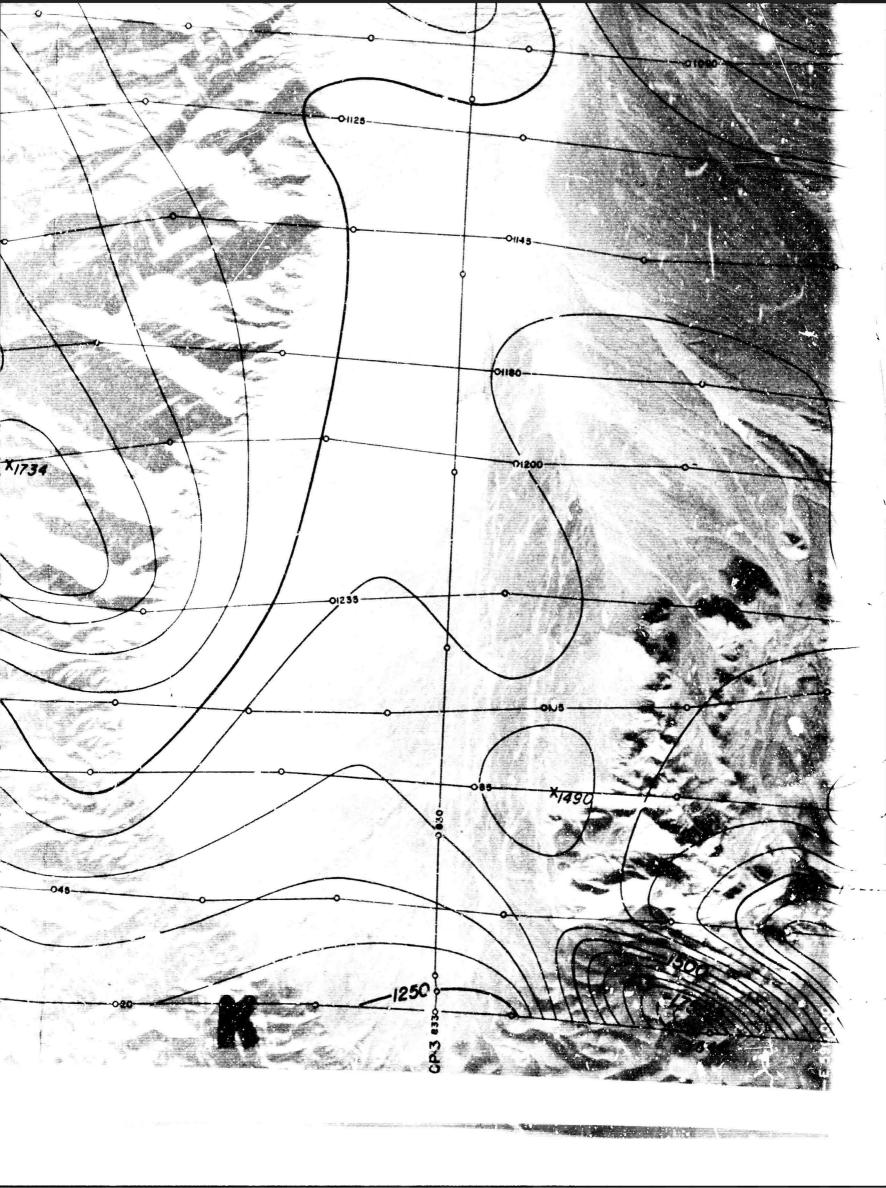


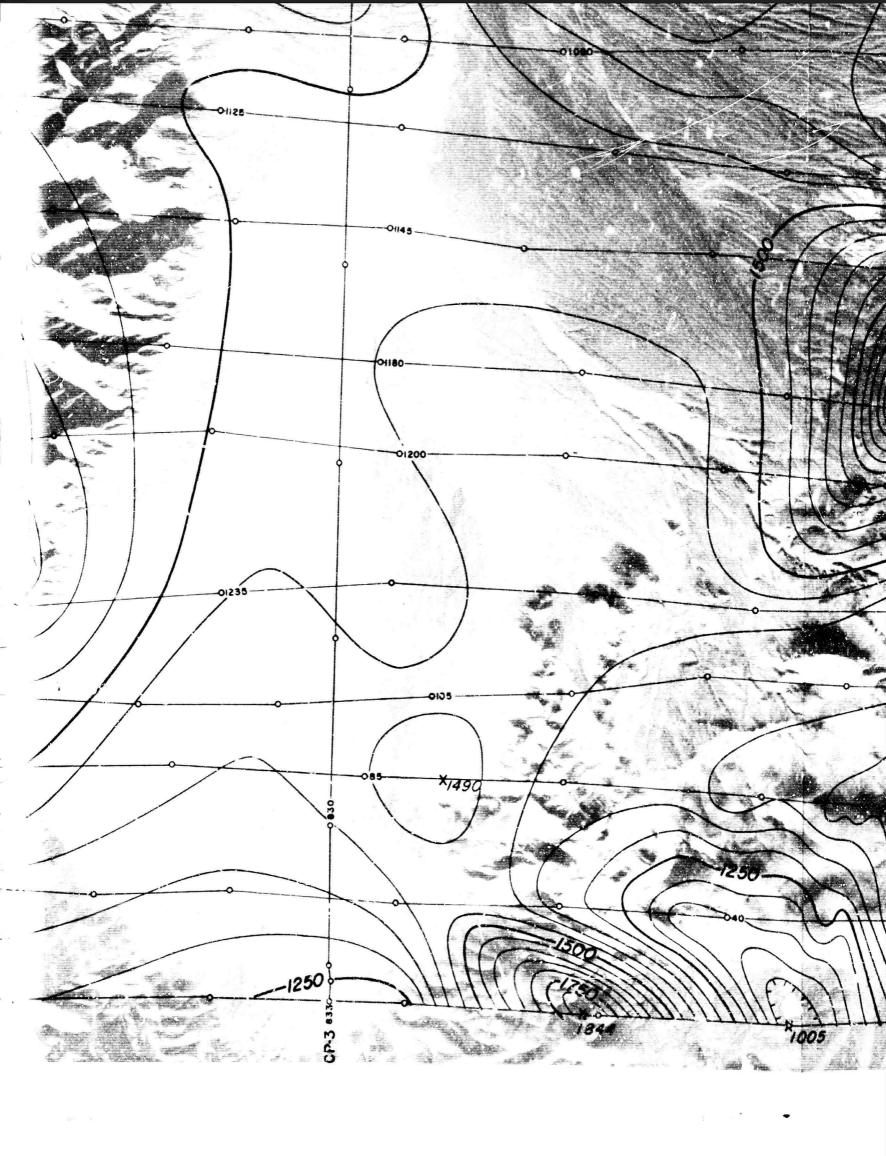


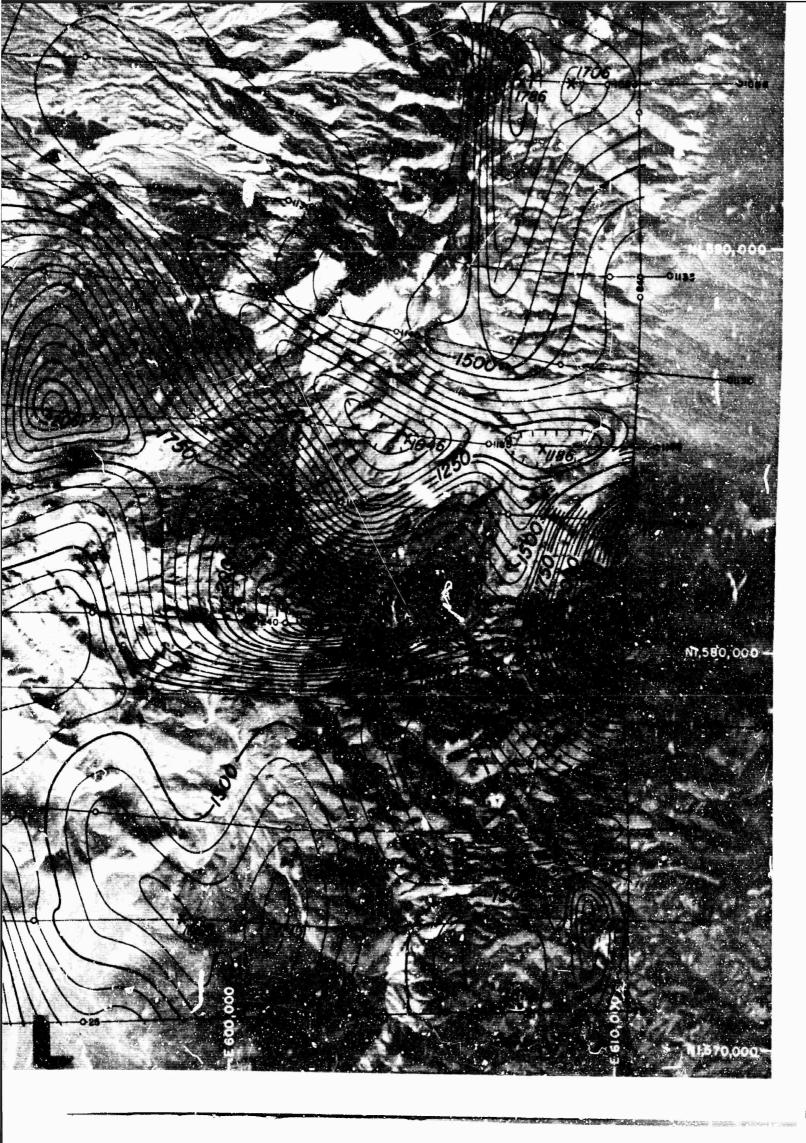


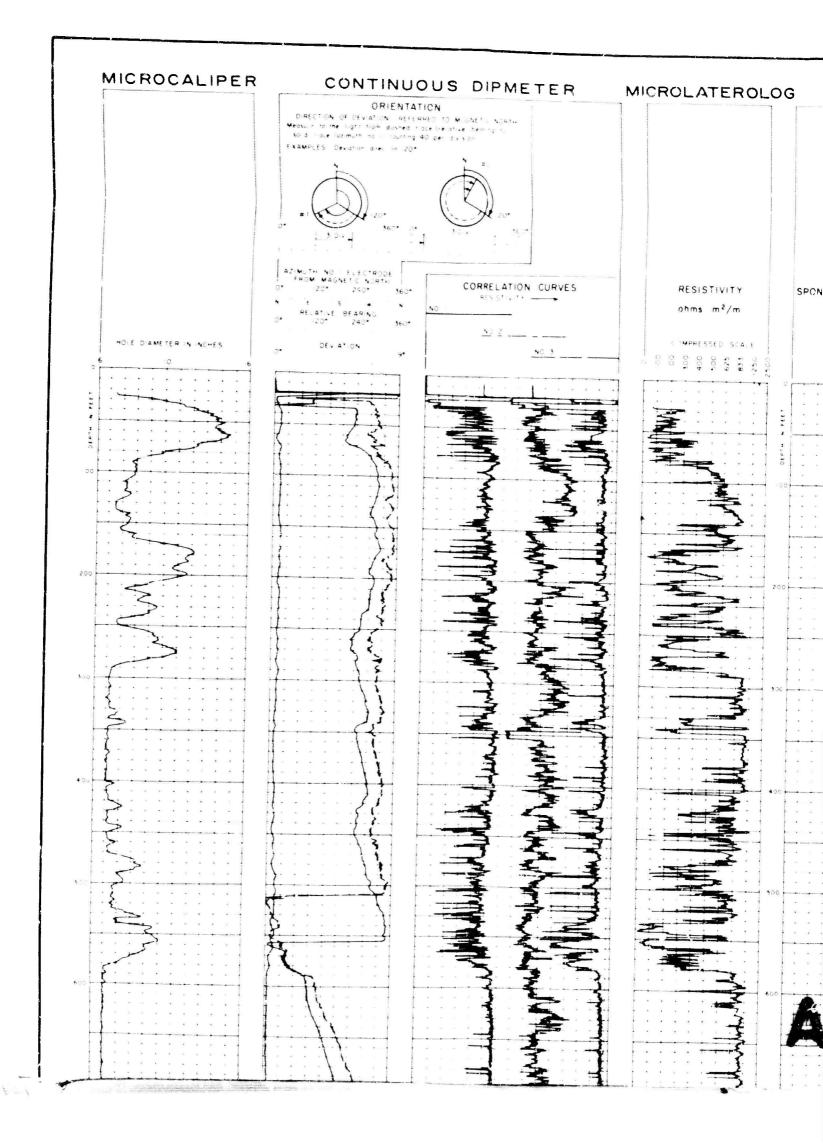


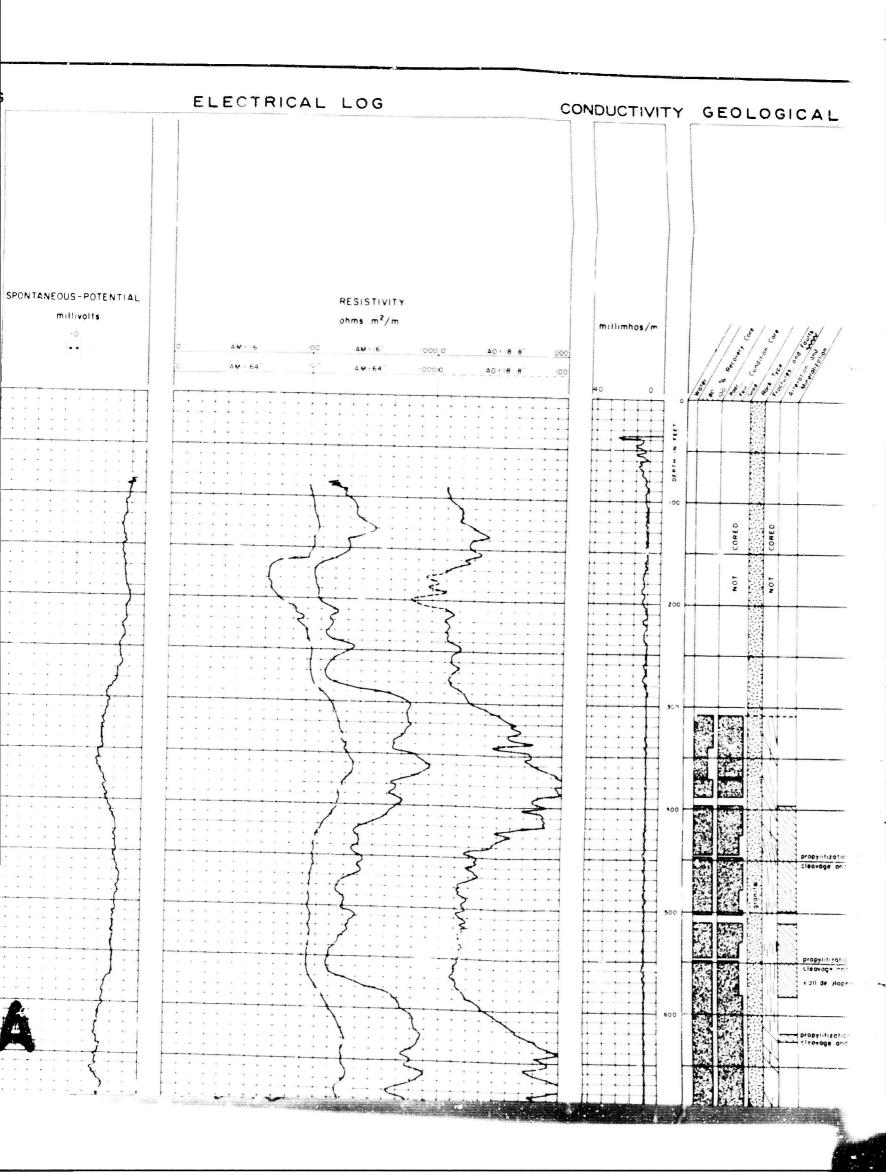


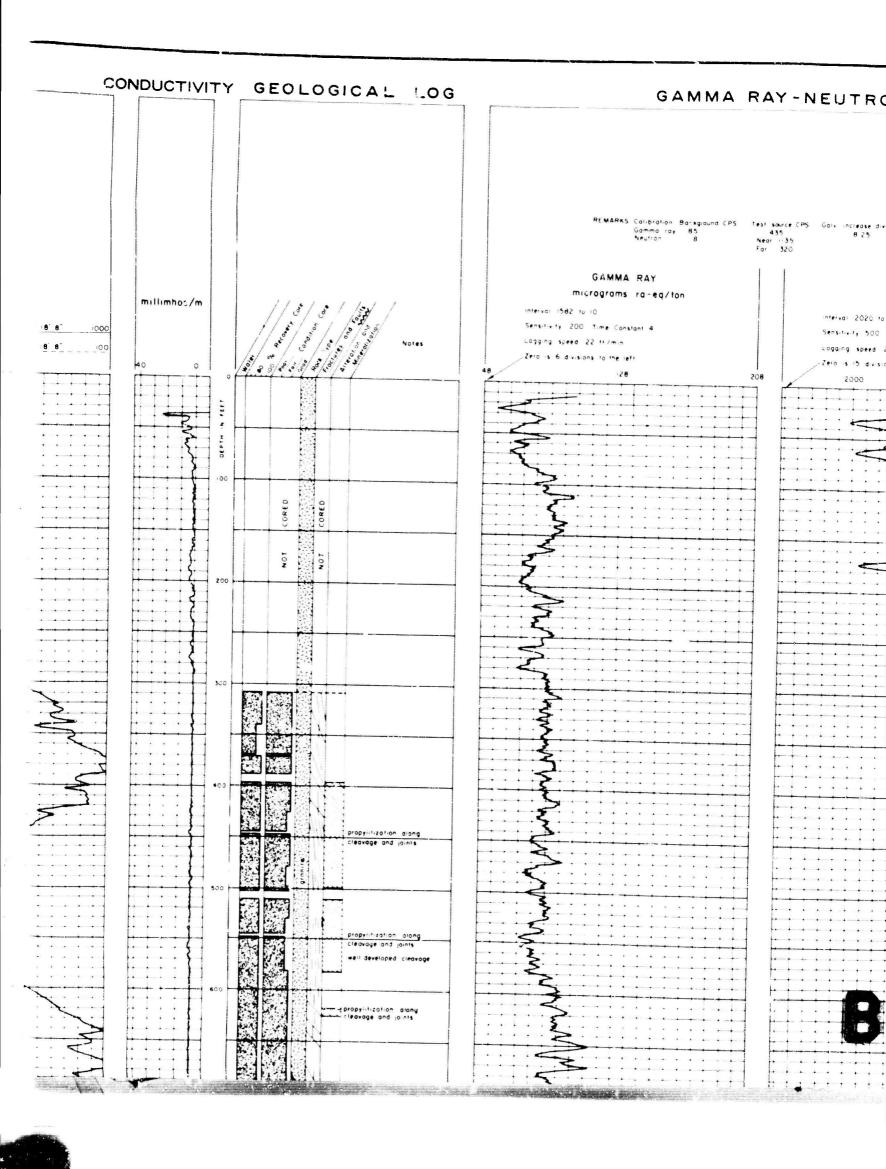


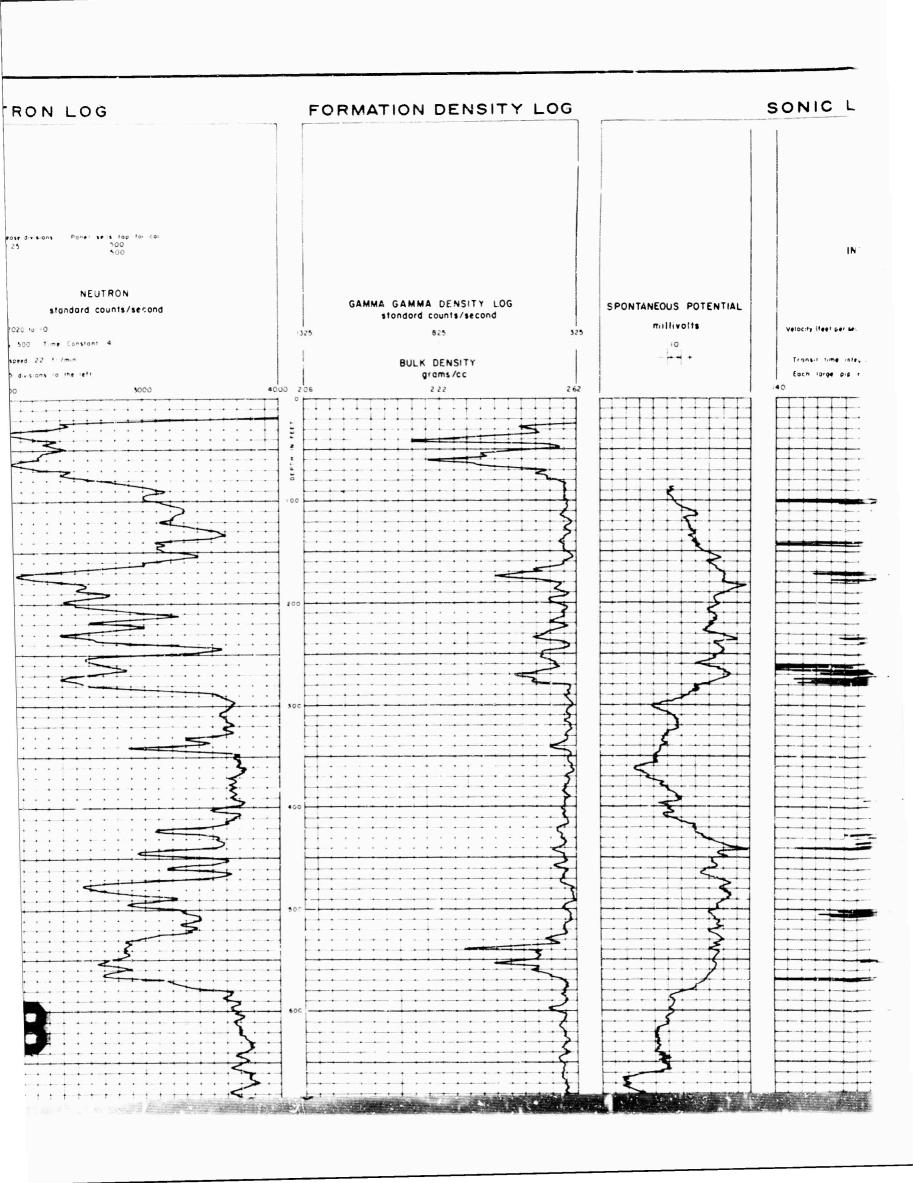


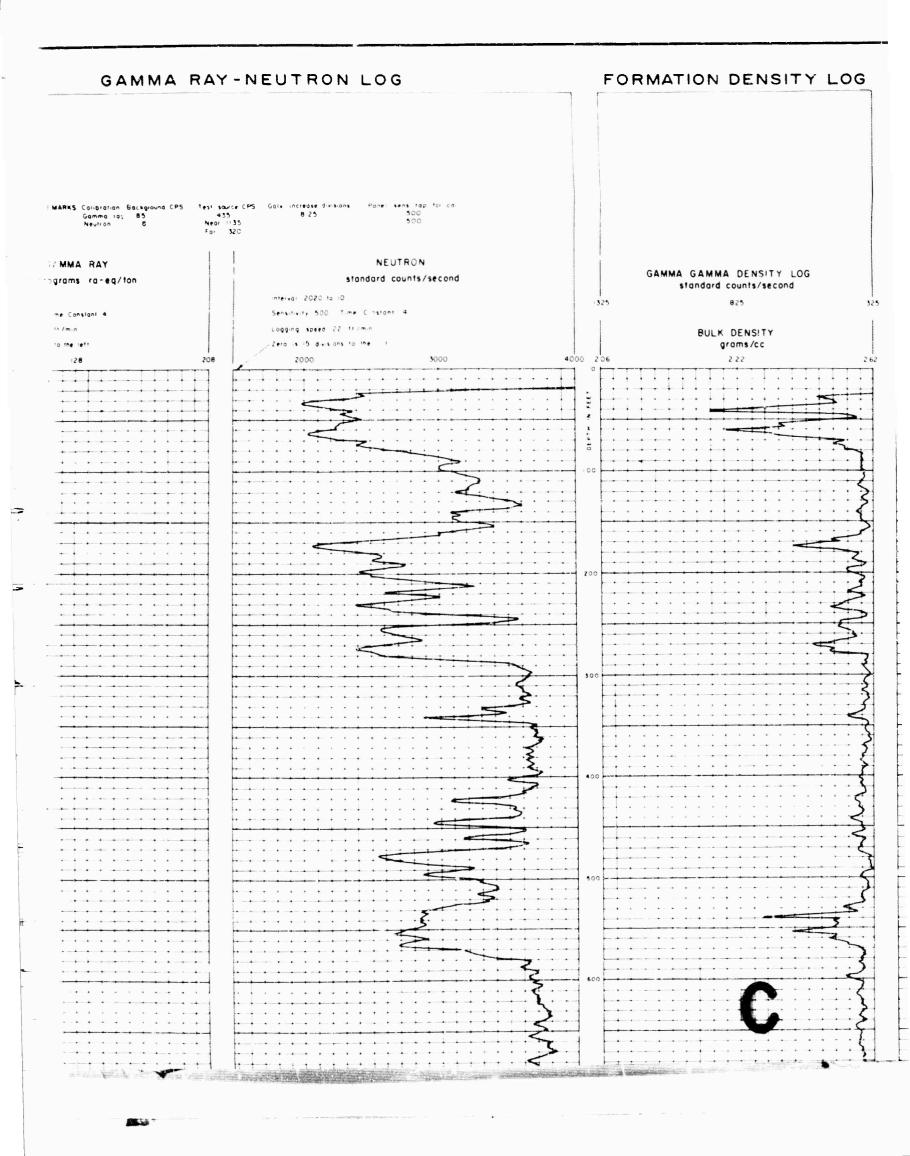








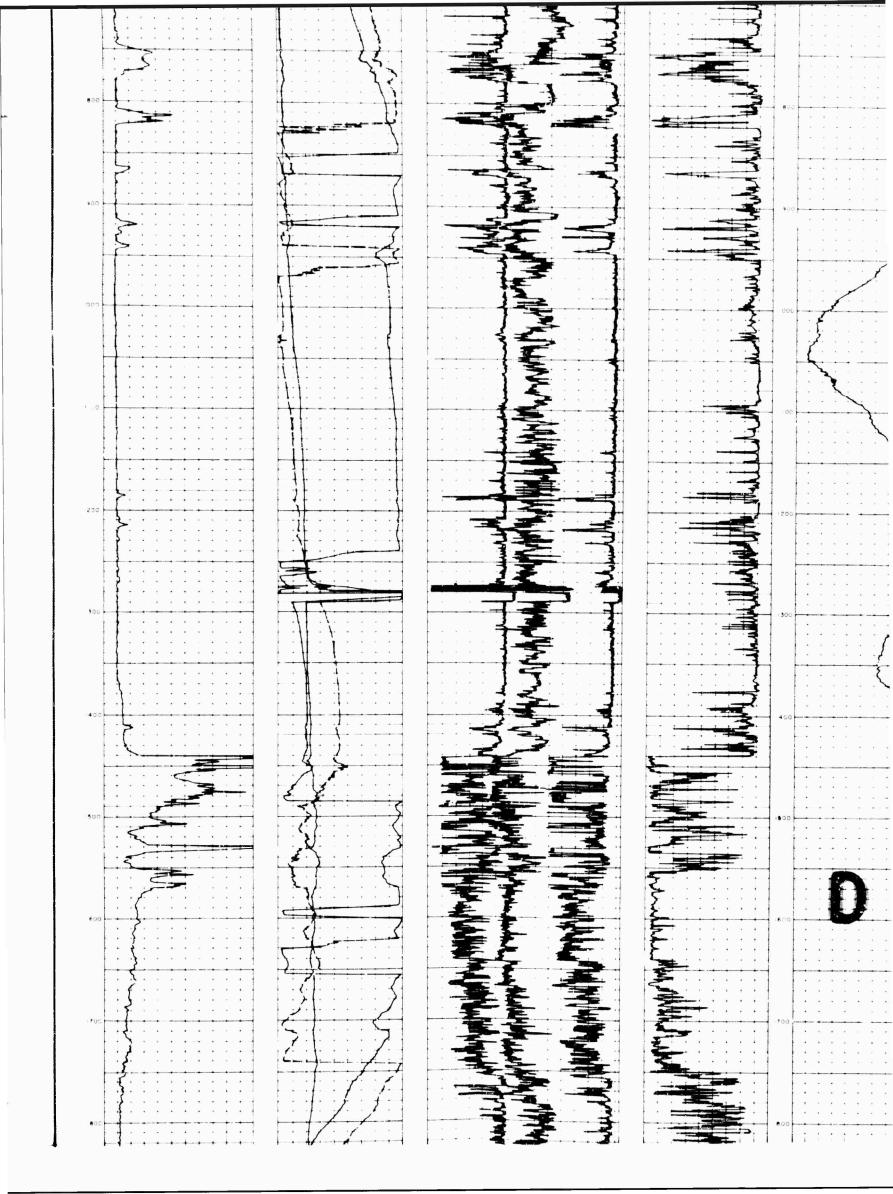


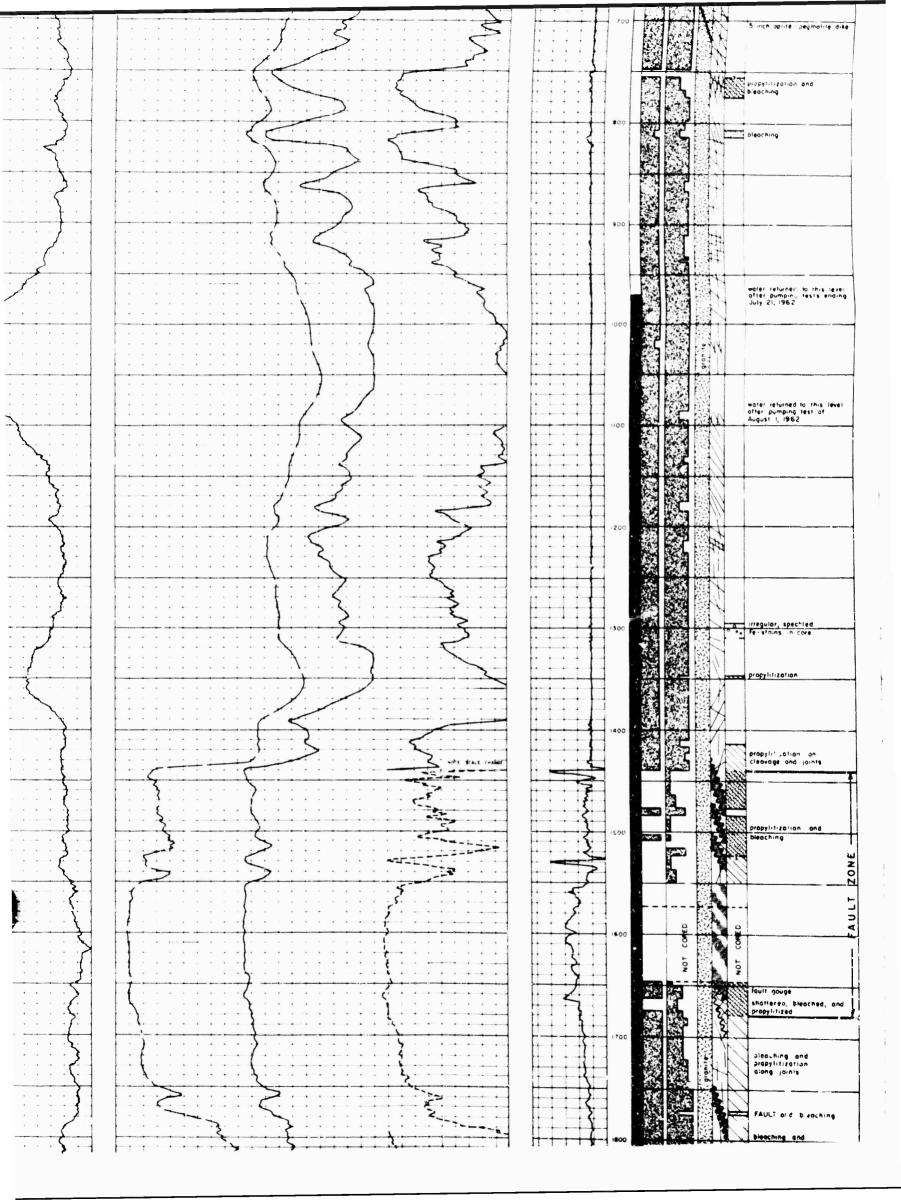


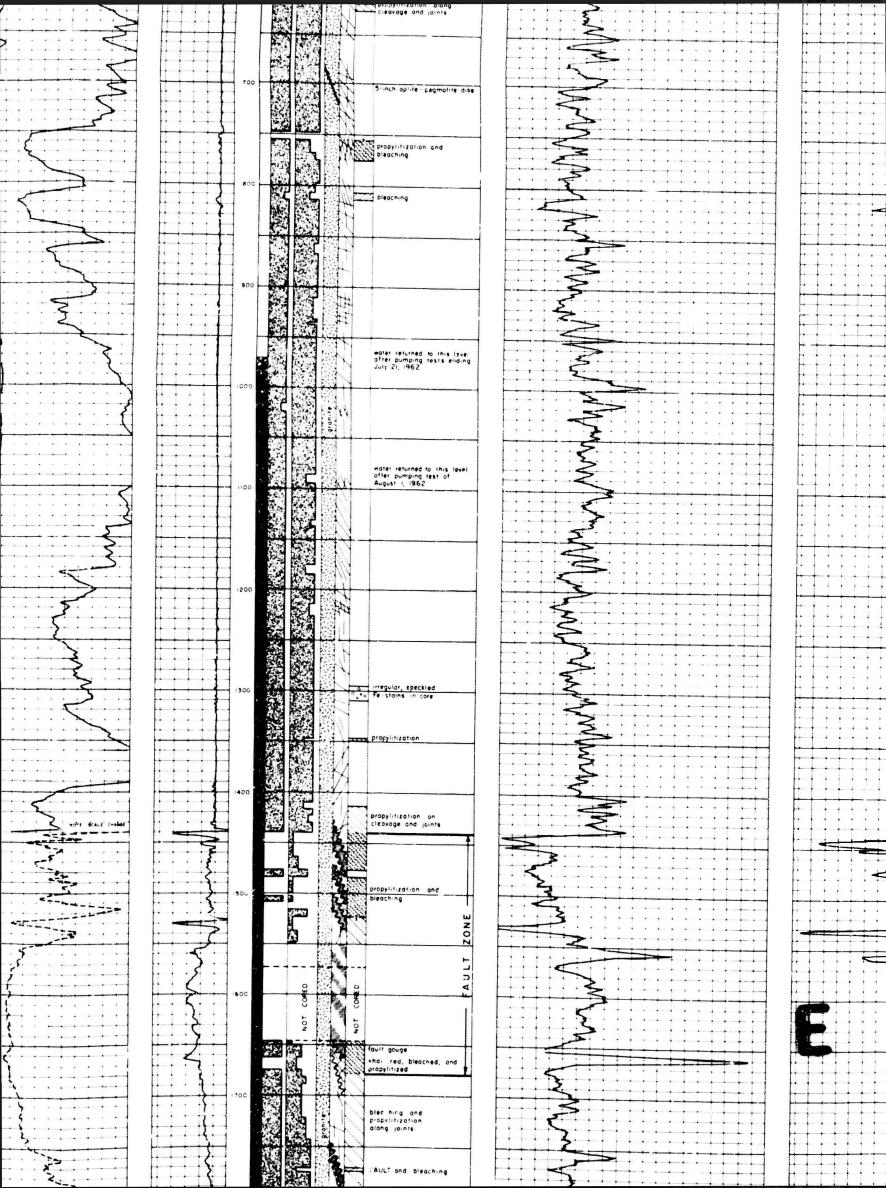
GENERAL DATA GEOPHYSICAL LOGS

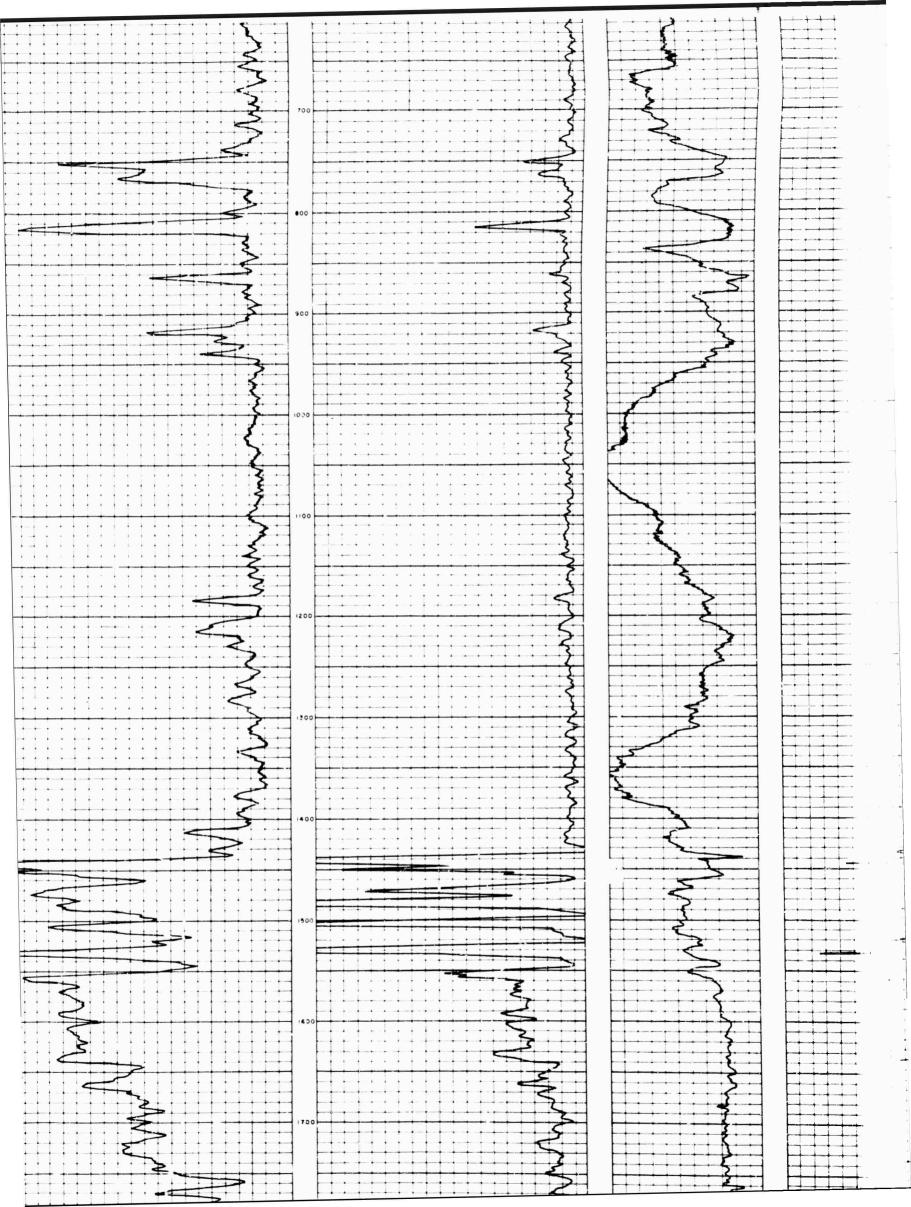
Date: 24 August 1962
Depth reached 2020'
Bottom dritter 2017'
Bit size 6"
Csg size 7"
Csg dritter 20
Max rec temp 86*F
Depth datum R T
Mud not clay-get
Density 111 pounds
Viscosity 82
Fluid level full
Satistity PPM Ct 3200
Mud resist 19 ct 68*F
Mud res 8NT 15 at 86*F
Mud Rmt (C) 1 25 at 86*F
Mud Rmt (C) 1 25 at 86*F
Mud Rmt (C) 2 0 at 86*F

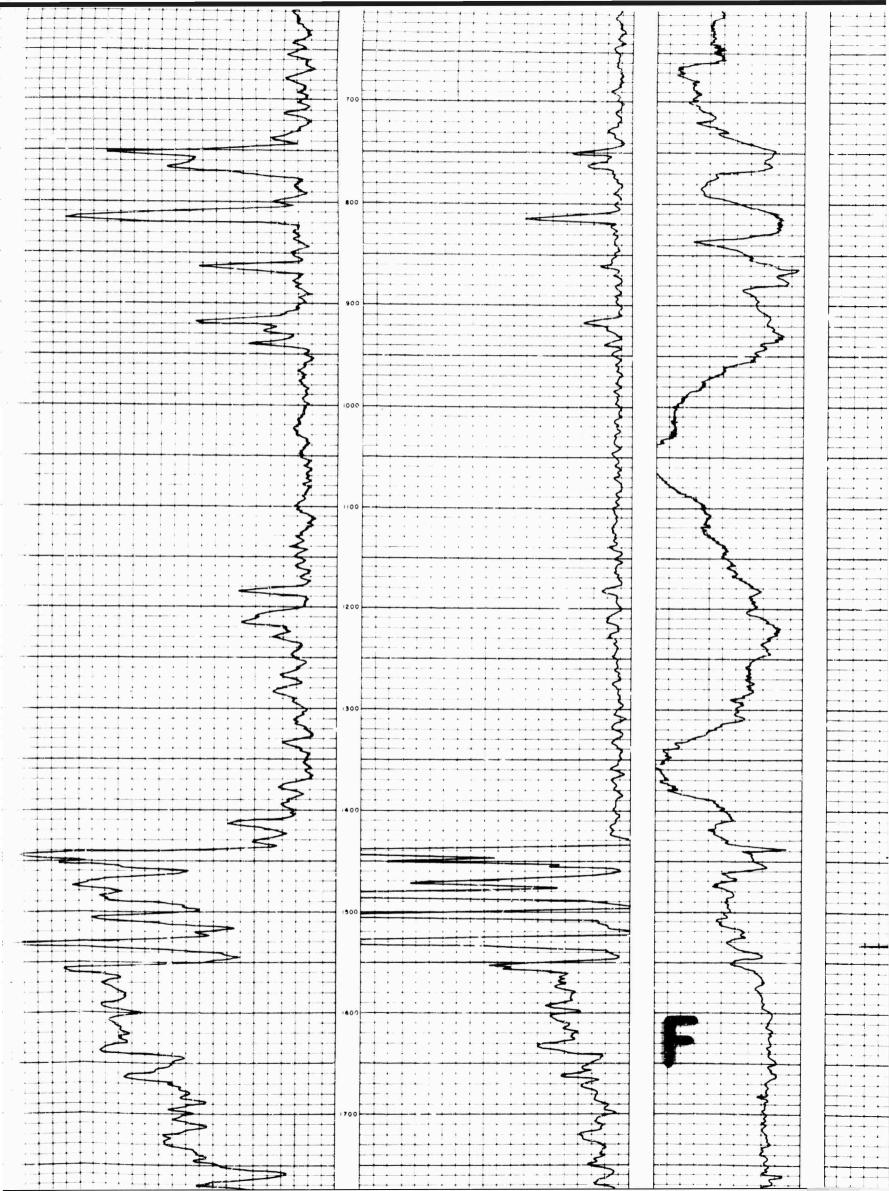
600

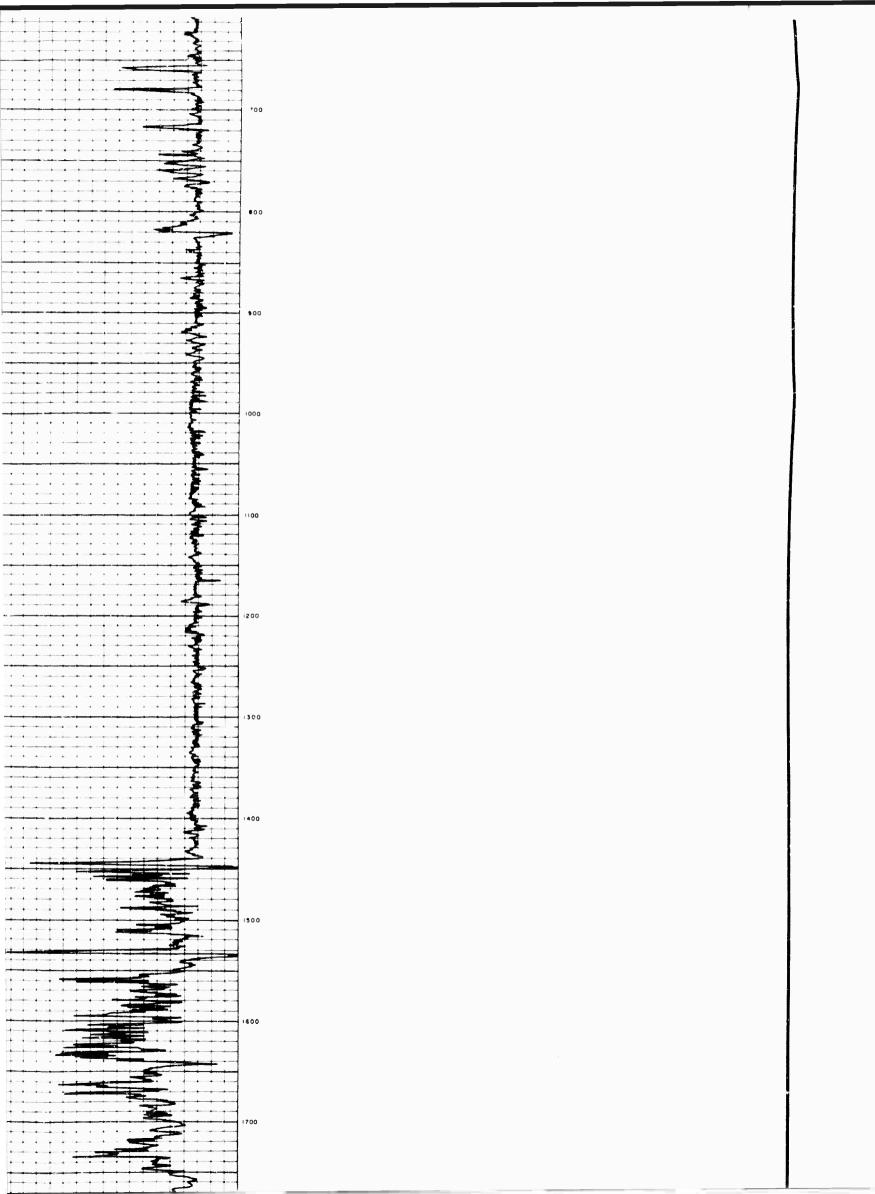


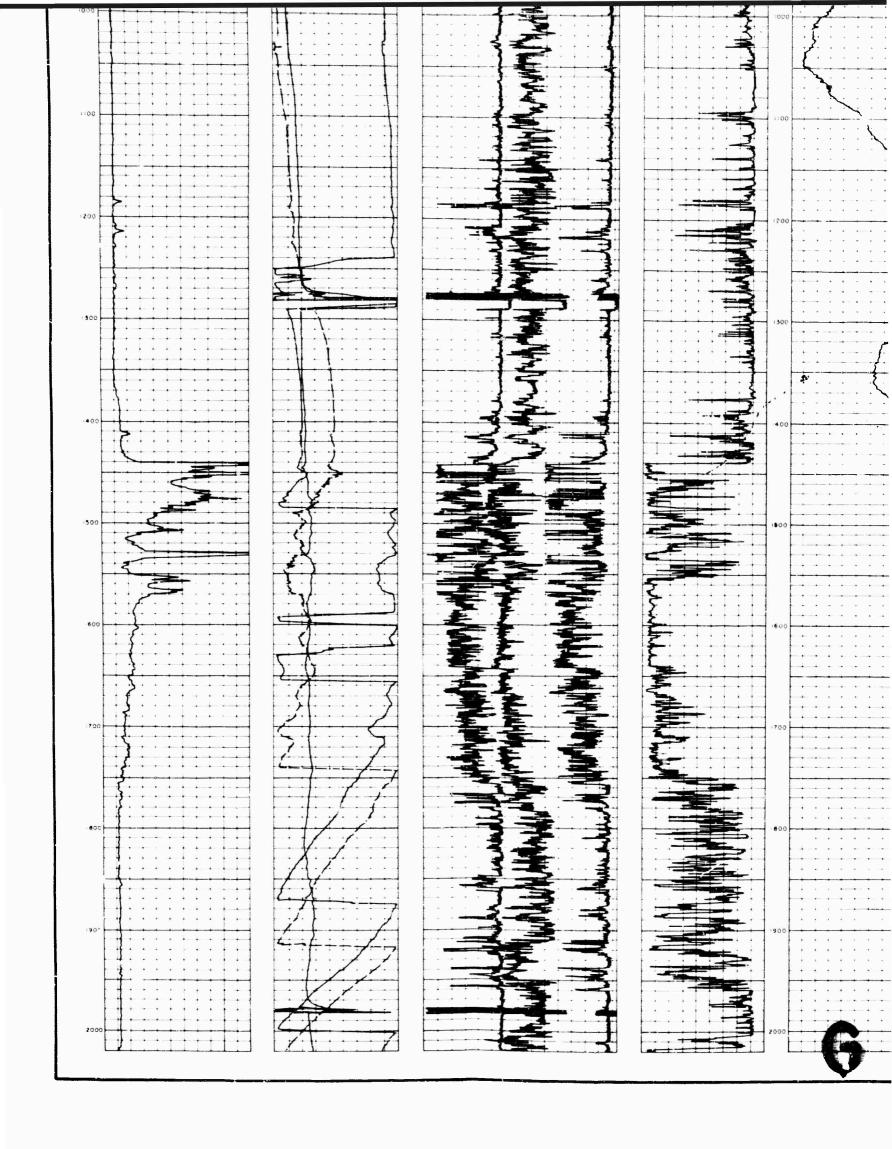


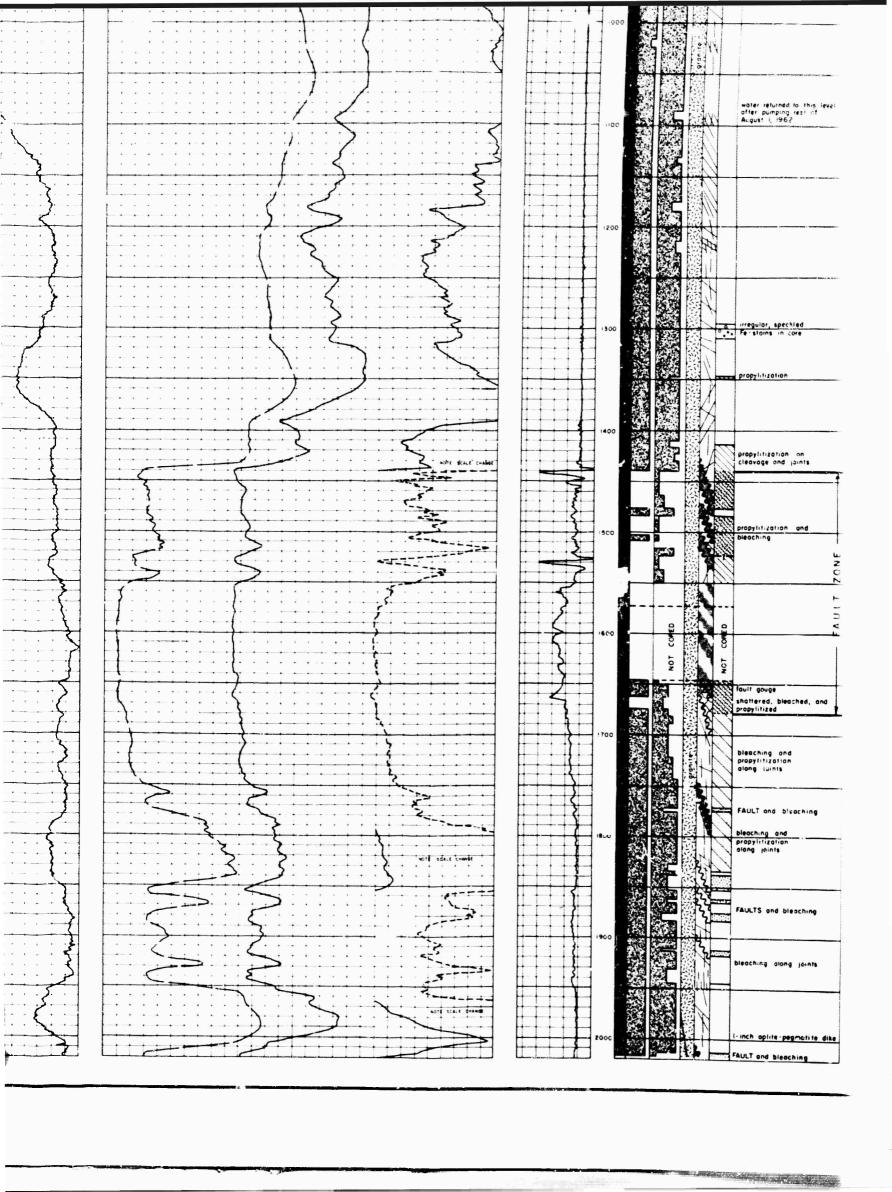


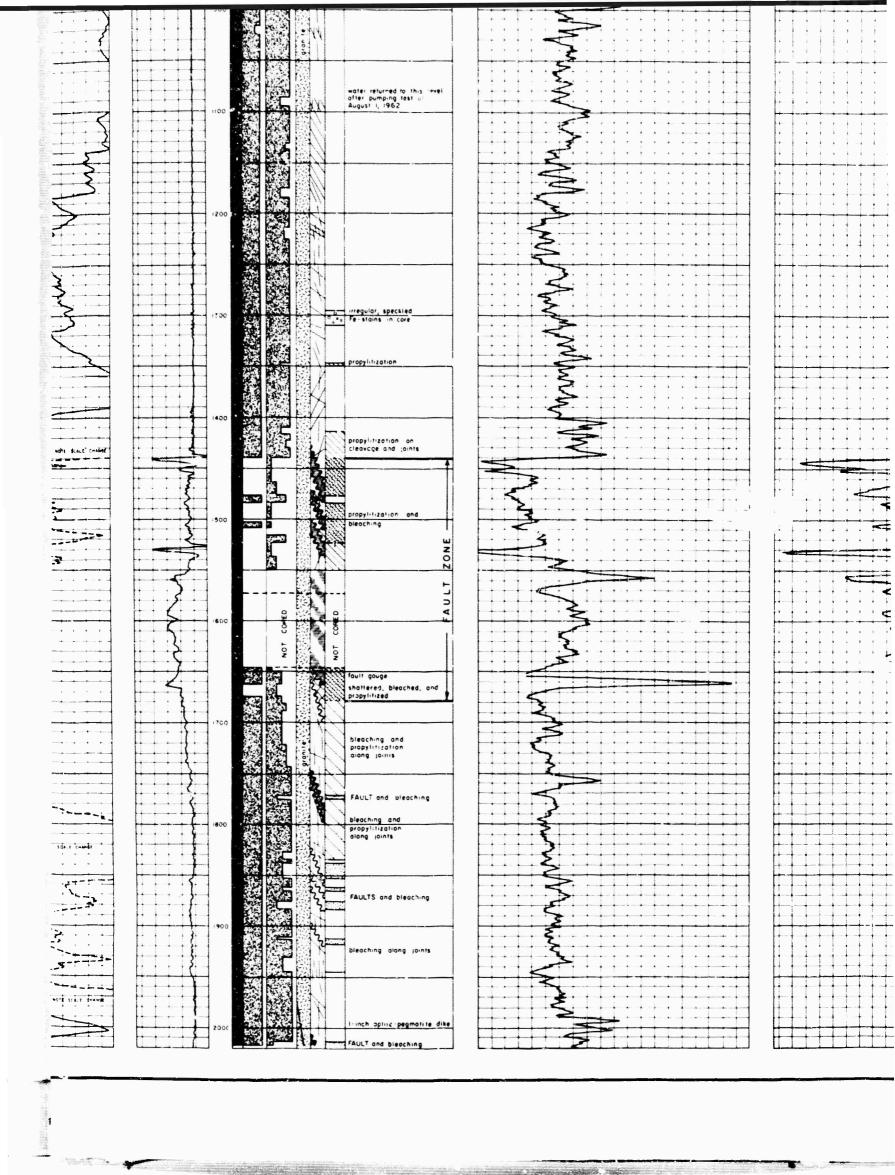


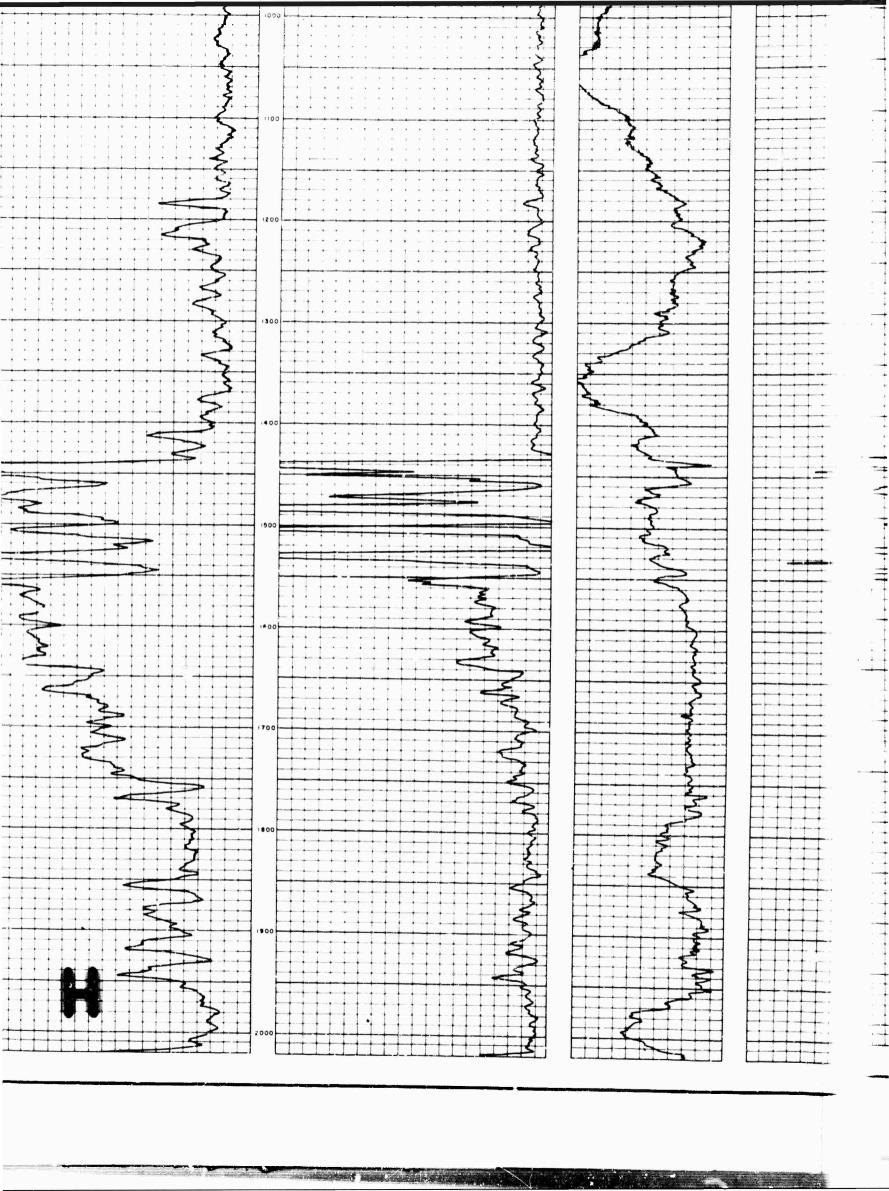


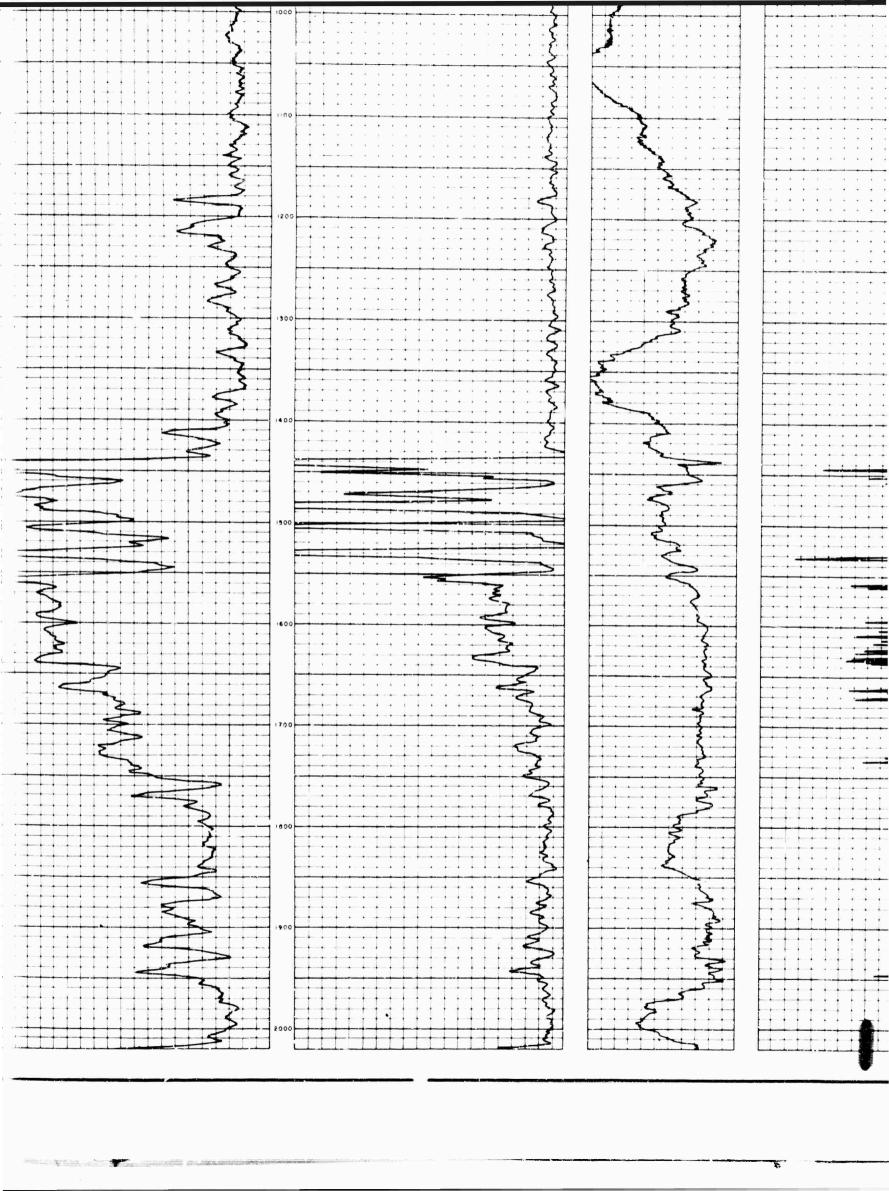


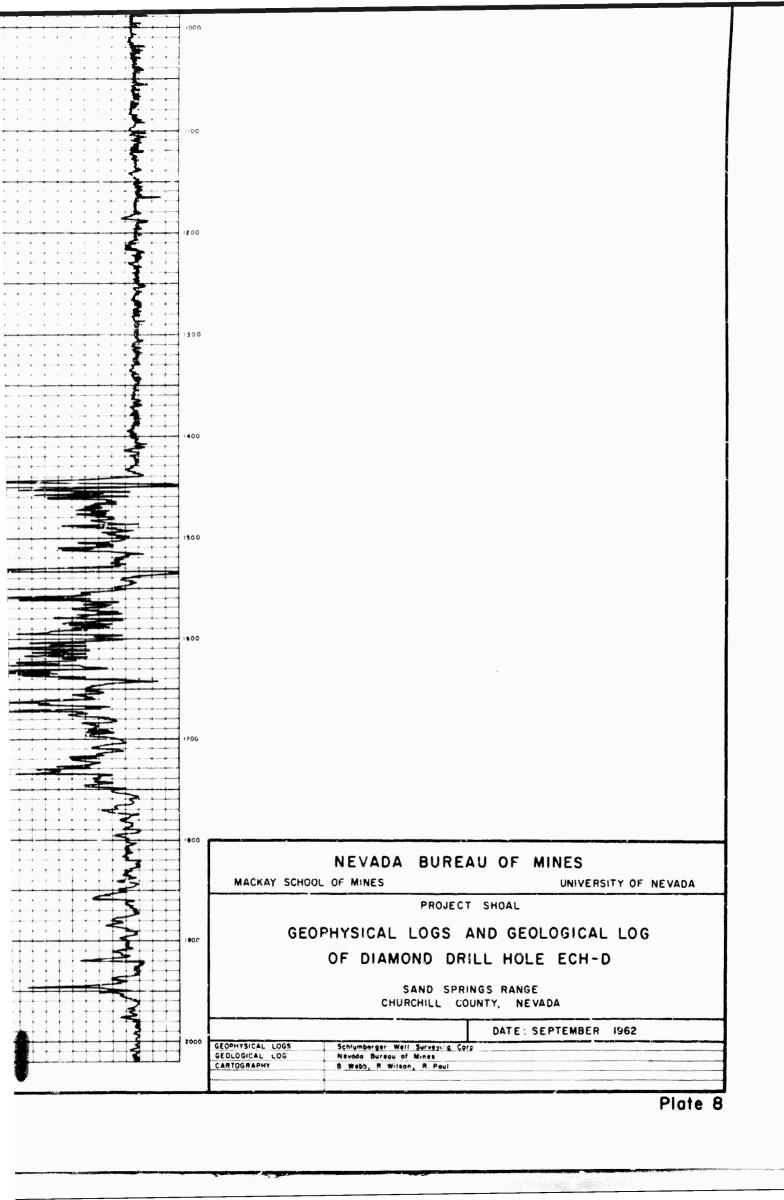


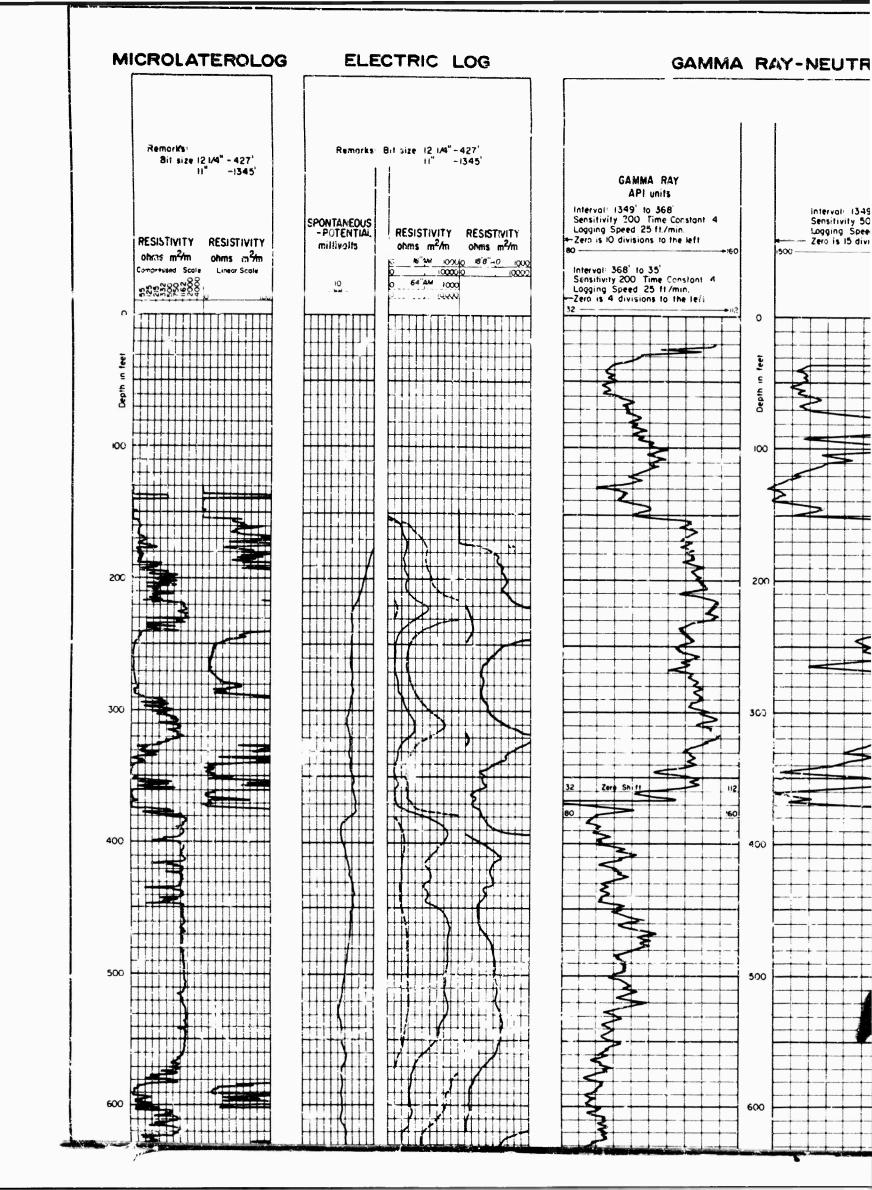




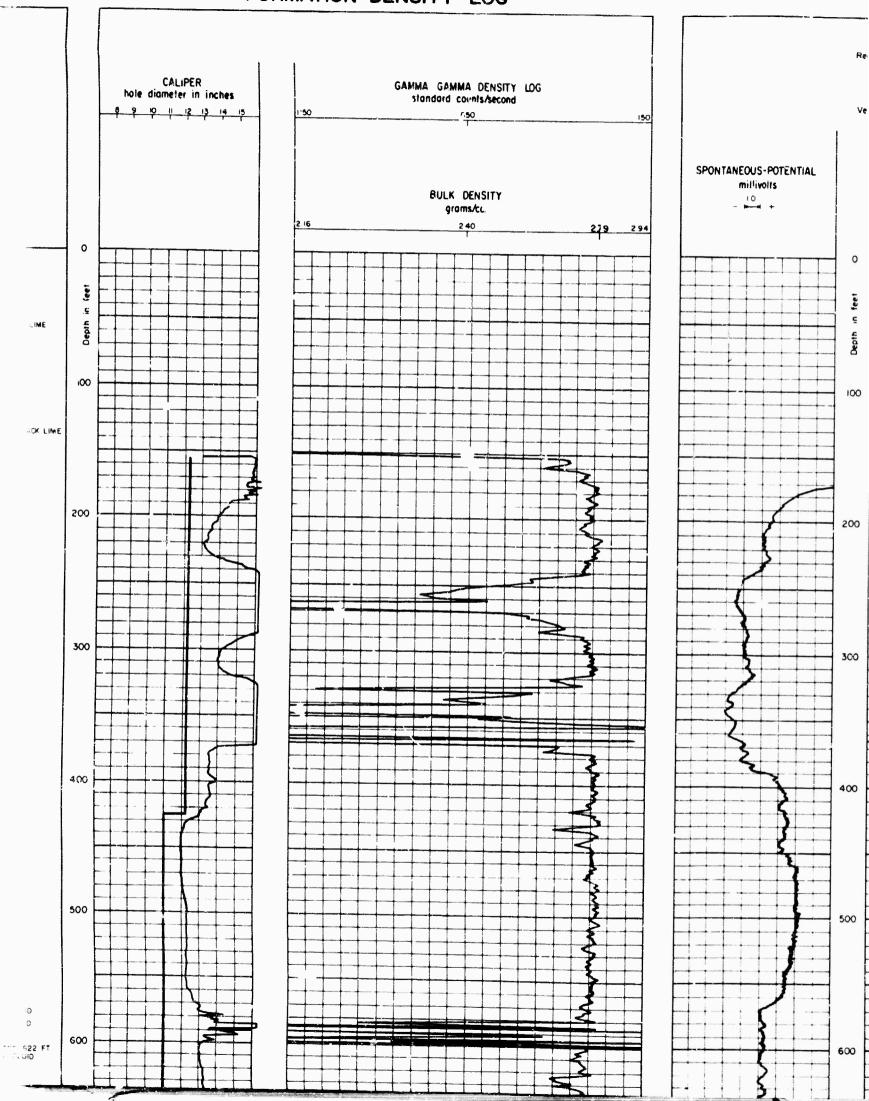






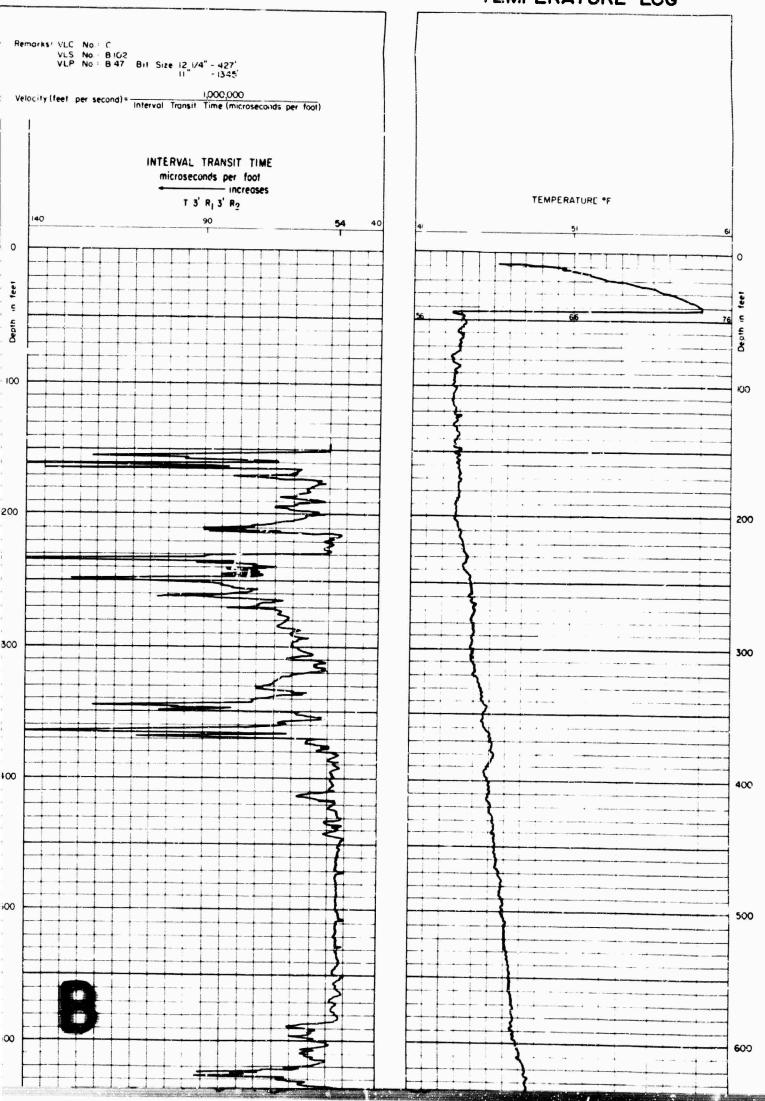


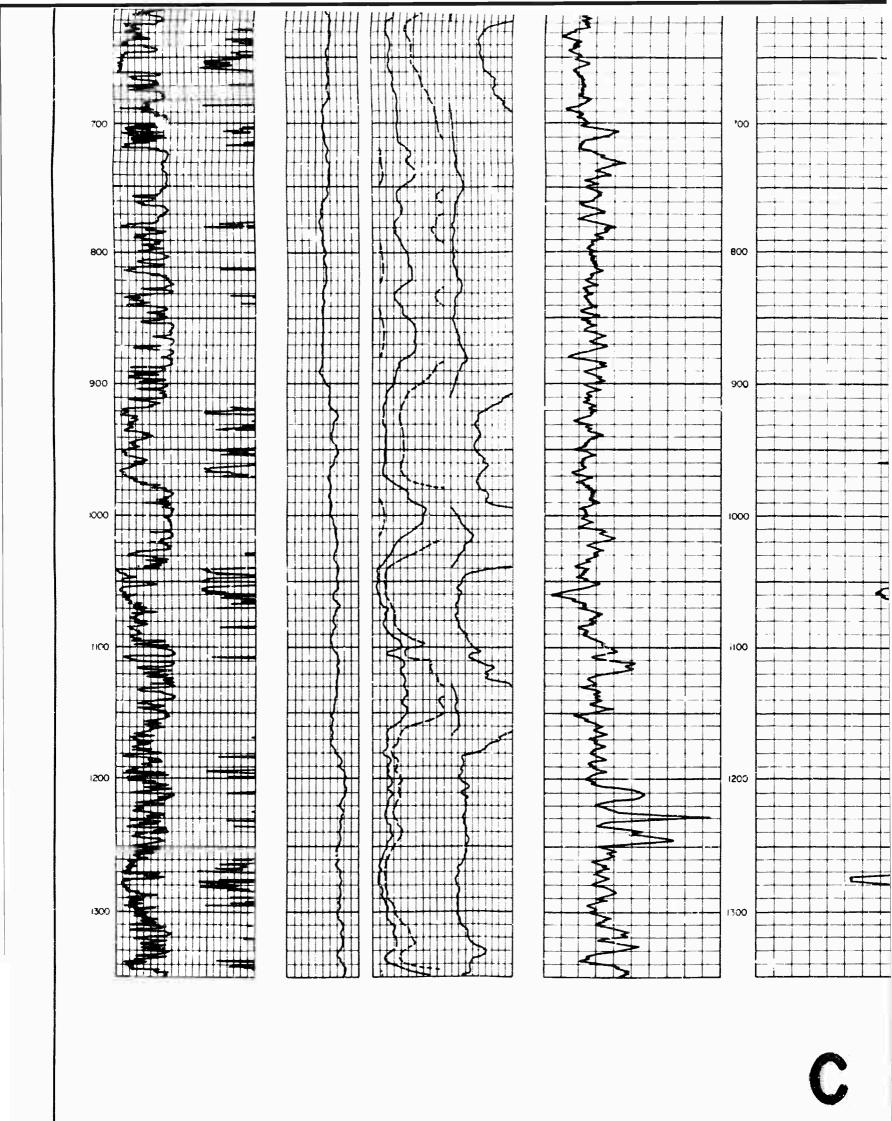
FORMATION DENSITY LOG

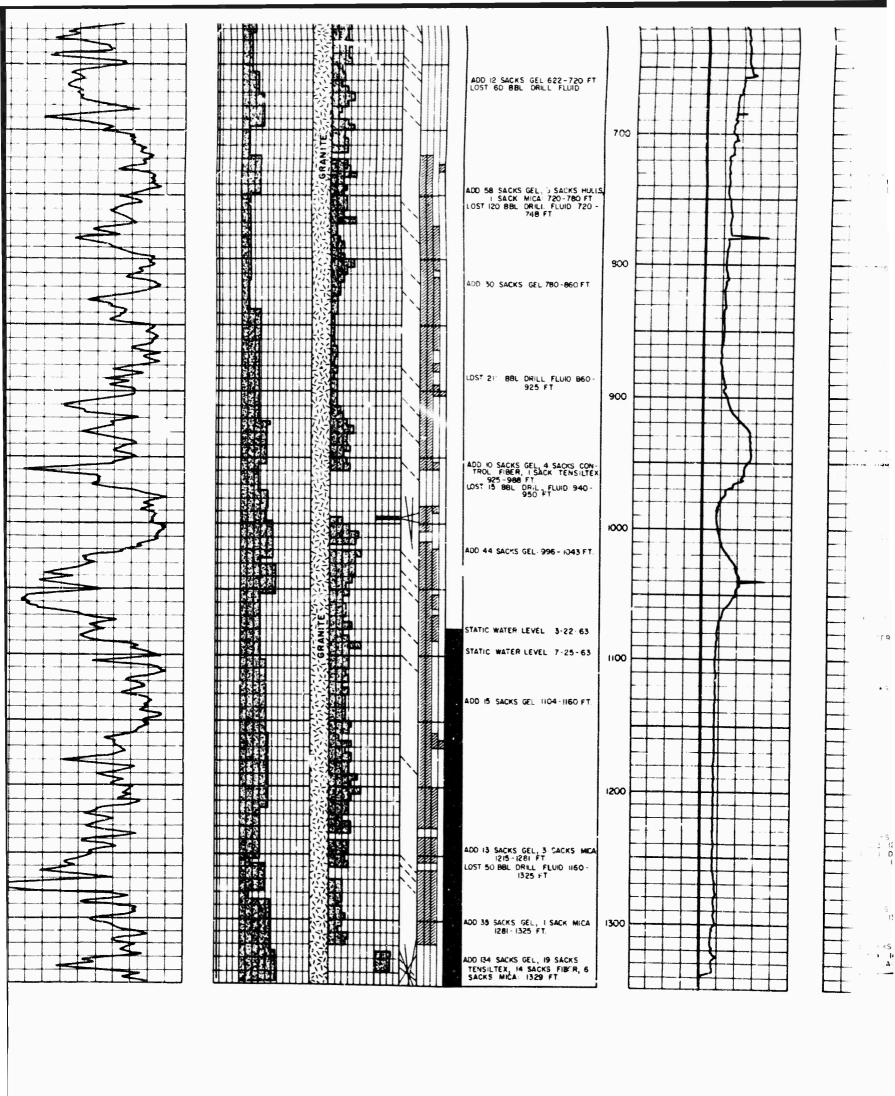


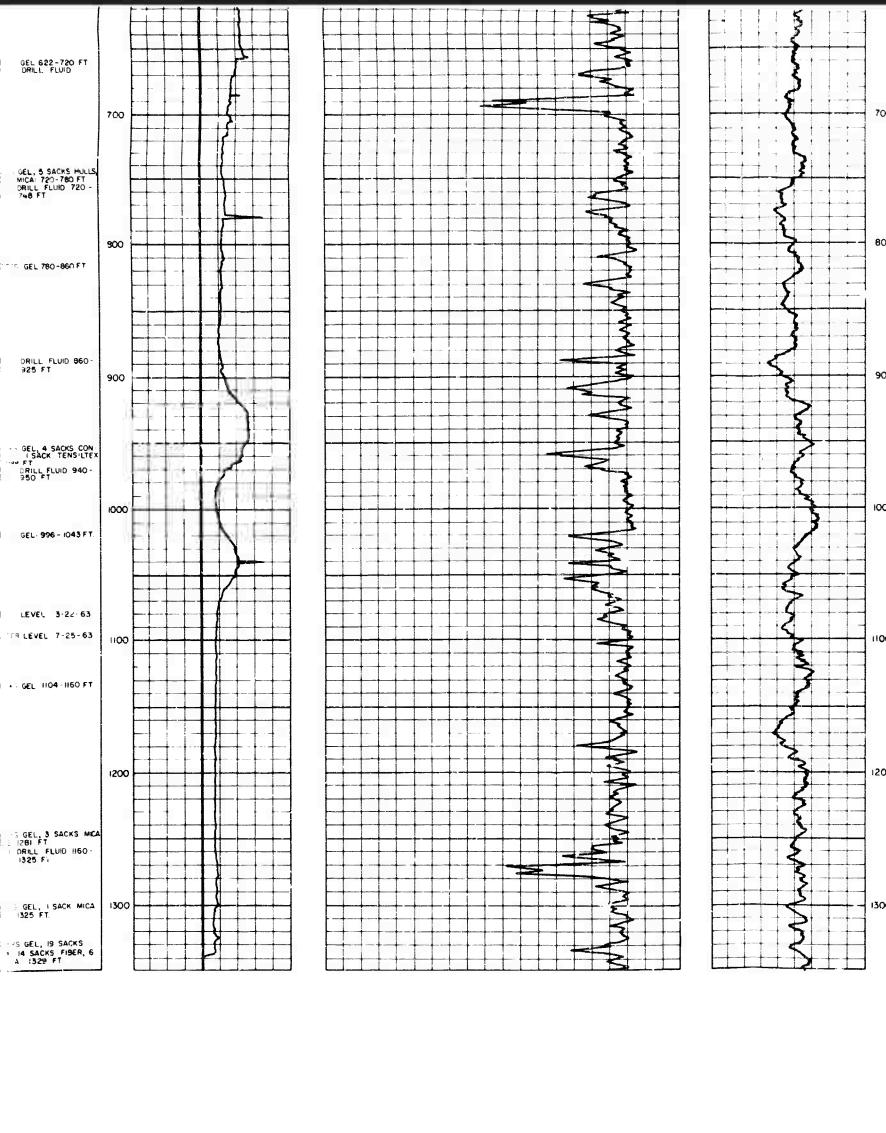
SONIC LOG

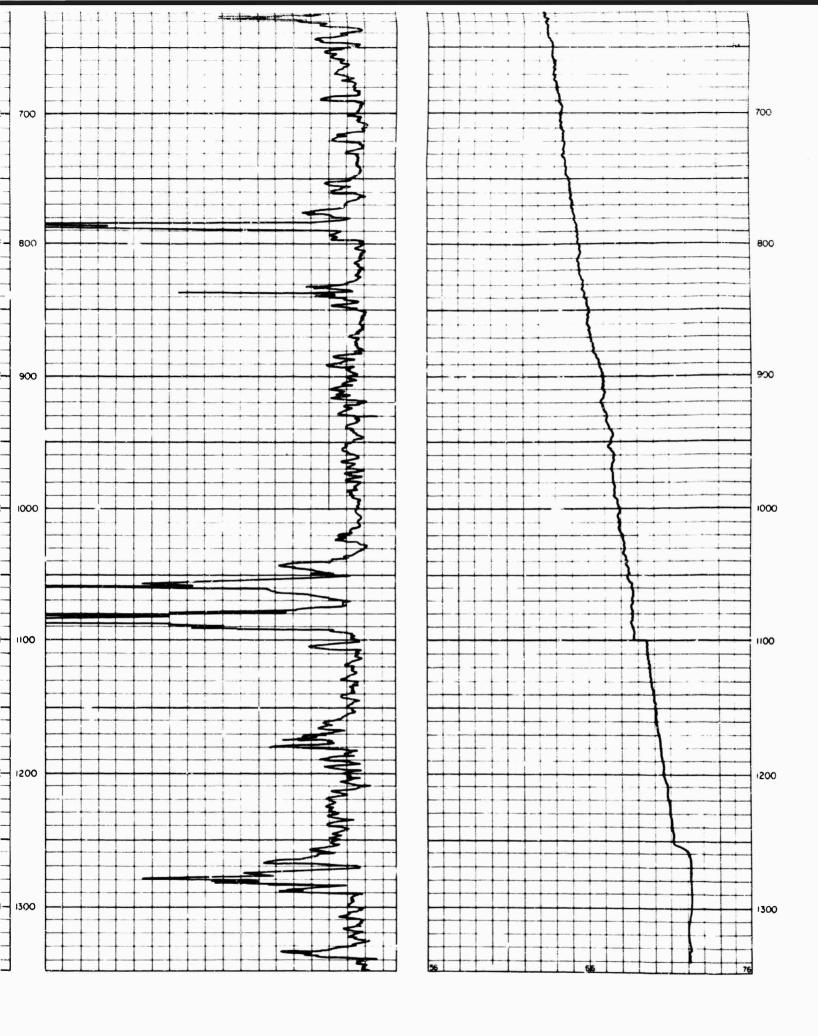
TEMPERATURE LOG







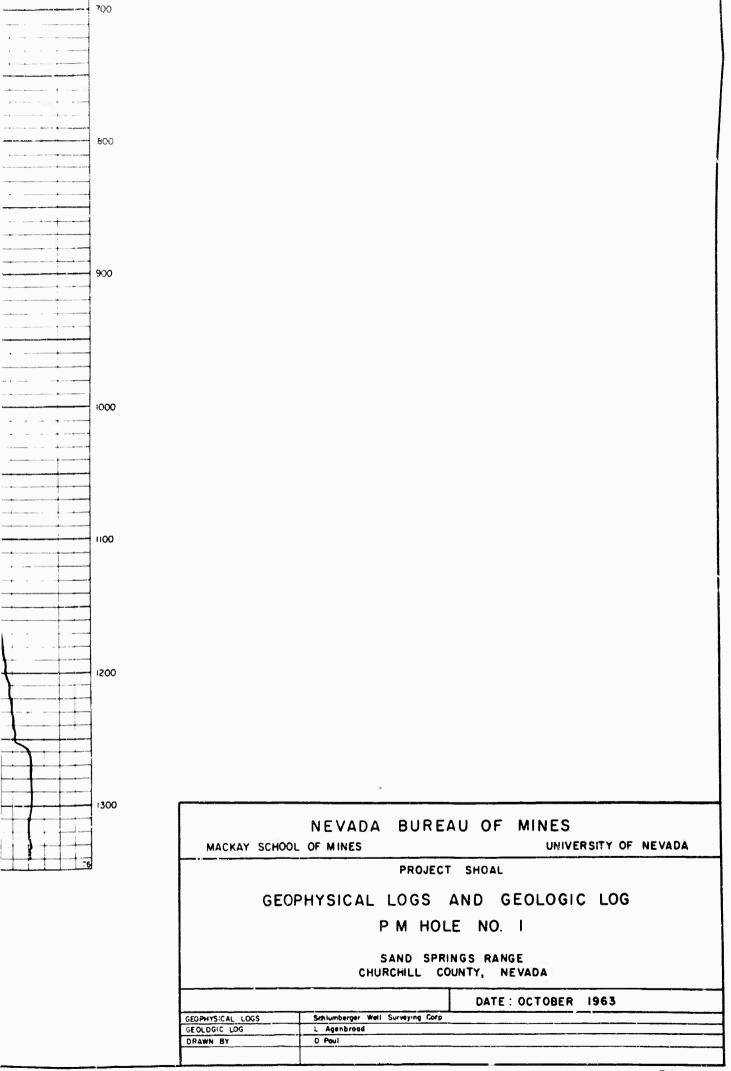


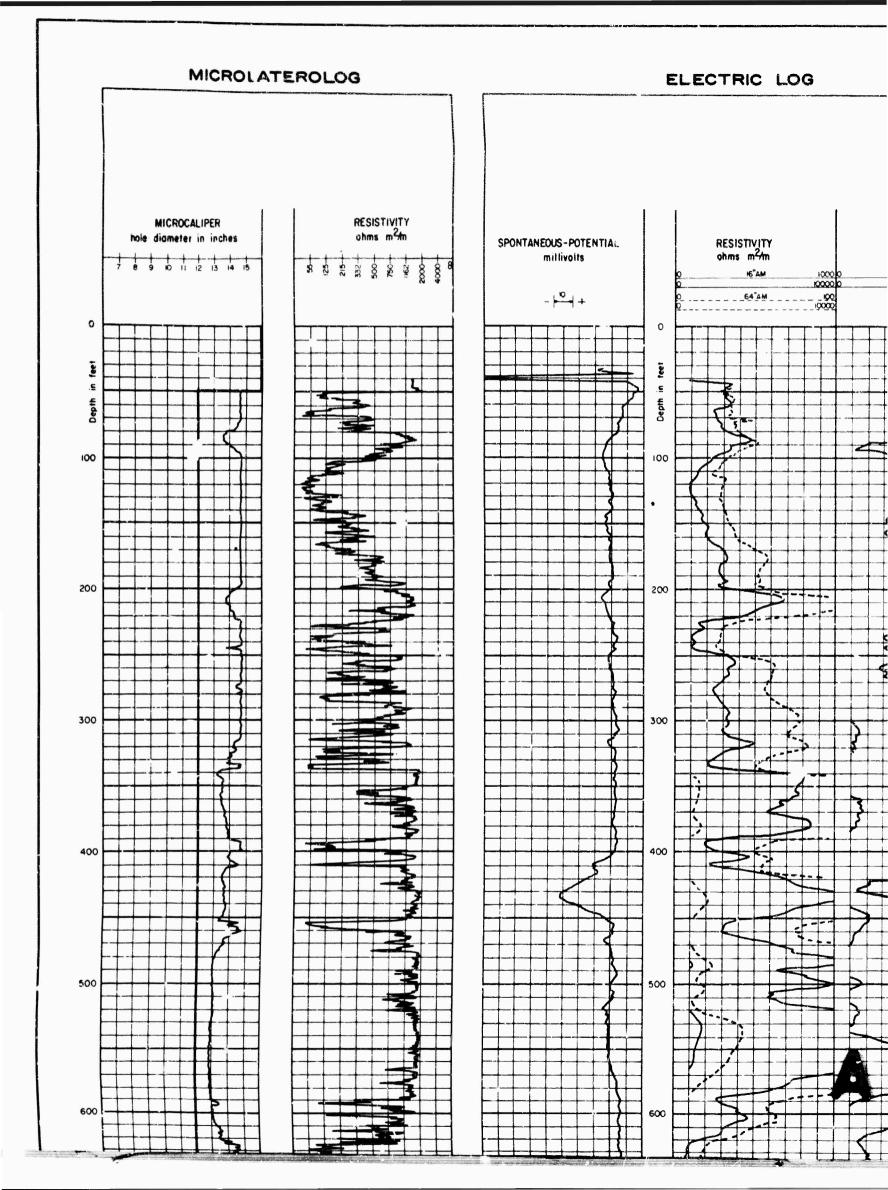


D

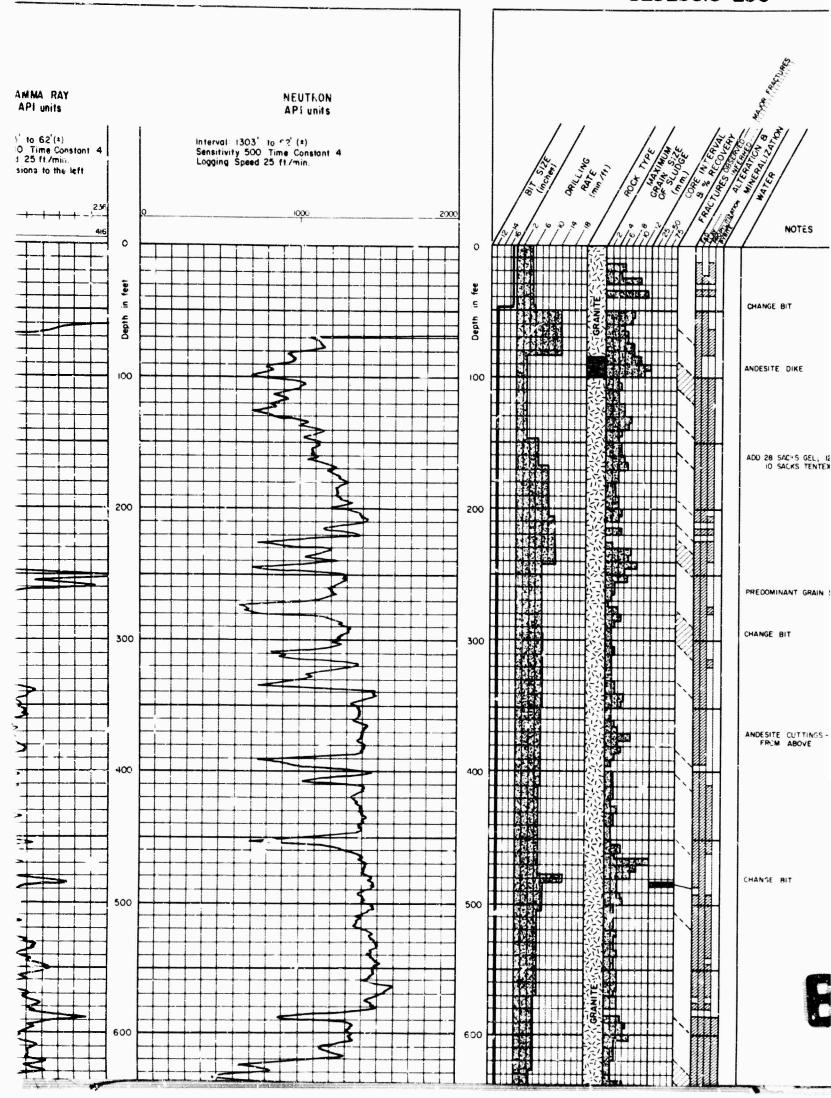


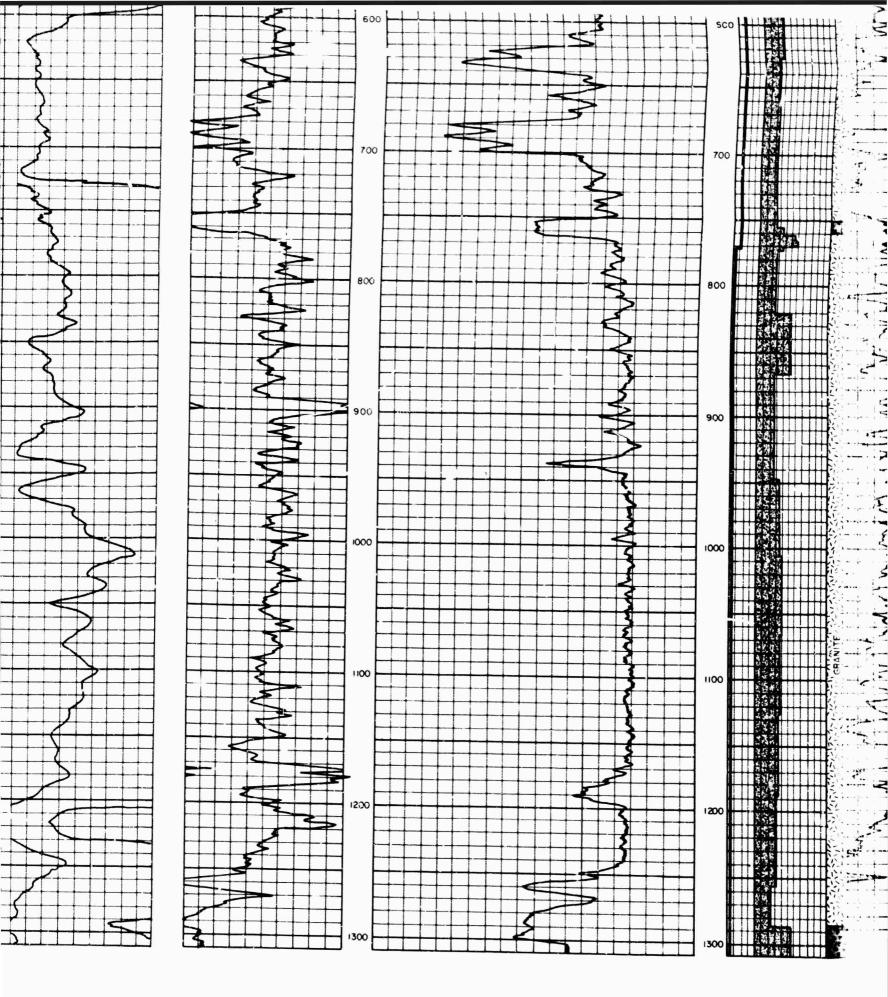
E



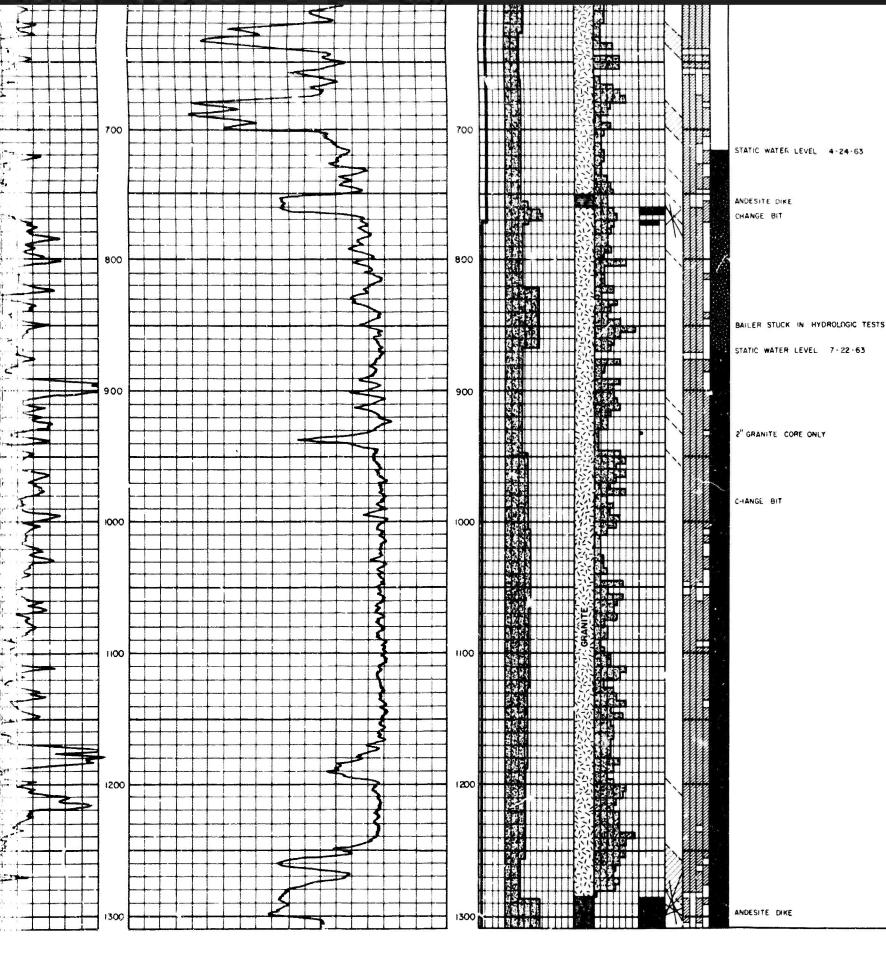


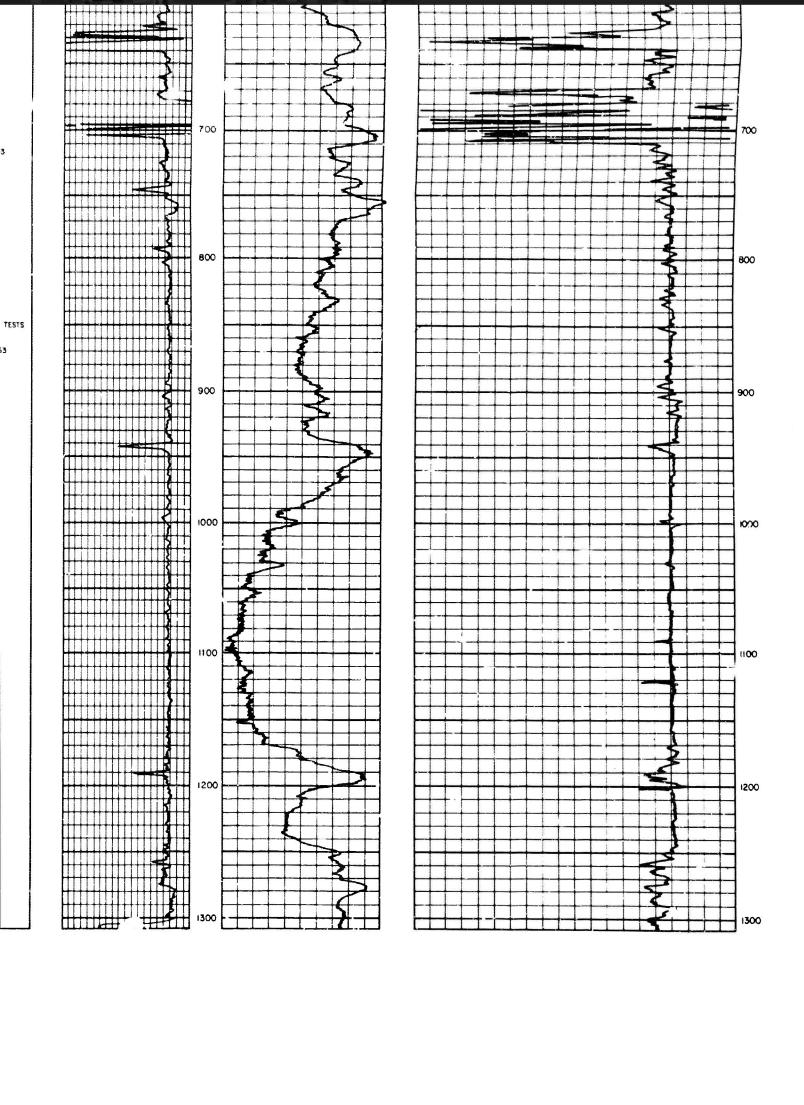
GAMMA RAY-NEUTRON LOG **NEUTRON** GAMMA RAY API units API units Interval: 1303' to 62' (*) Sensitivity 500 Time Constant 4 Logging Speed 25 ft/min. Interval: (303) to 62 (*) Sensitivity 400. Time Constant: 4. Logging Speed: 25 (1/min. Zero is: 6 divisions to the left RESISTIVITY 10000 2000 1000 0 0 fect -2 .€ Depth 100 100 200 200 300 400 400 500 500 600 600

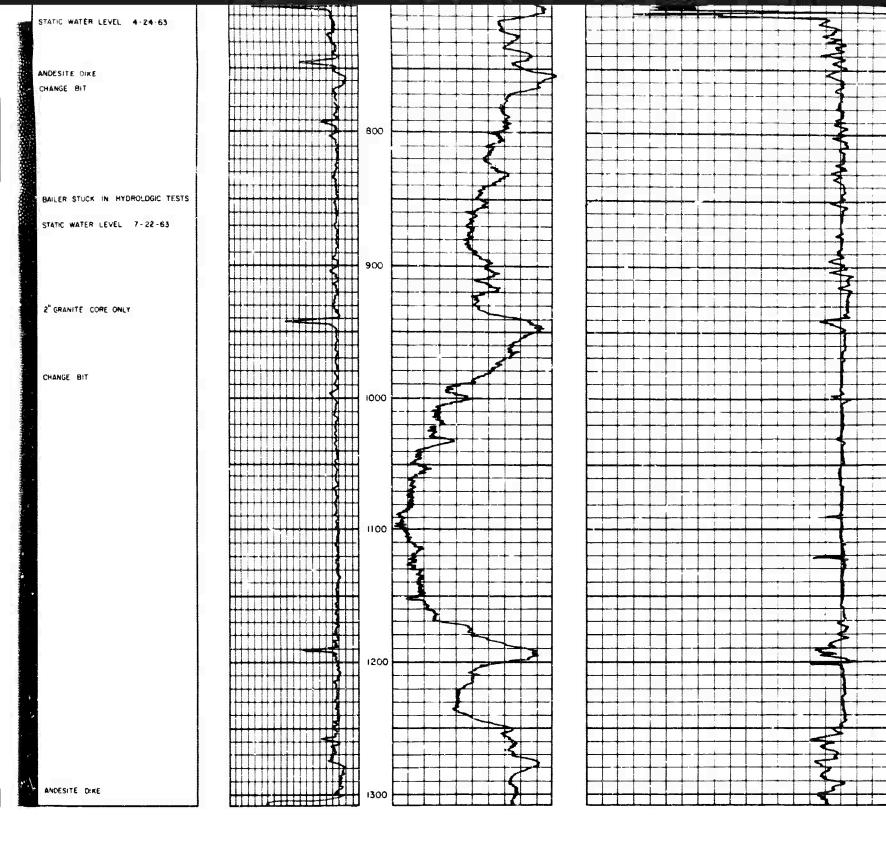




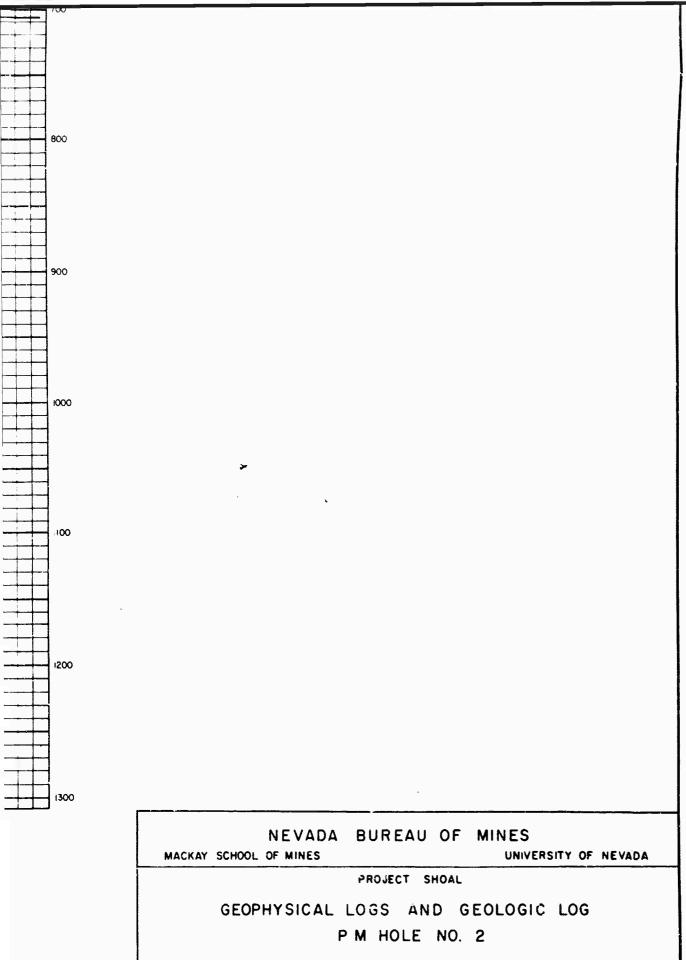
C





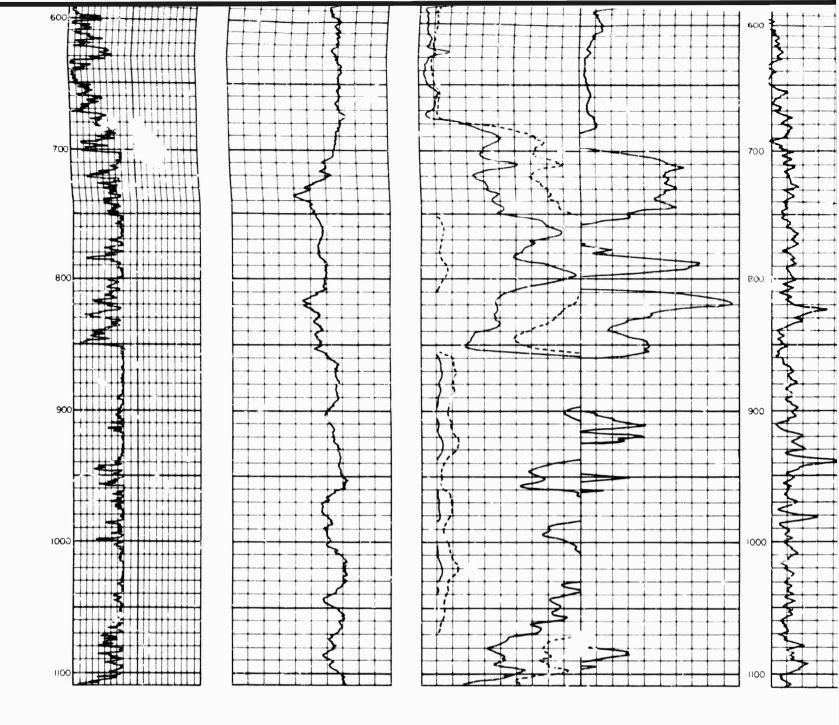


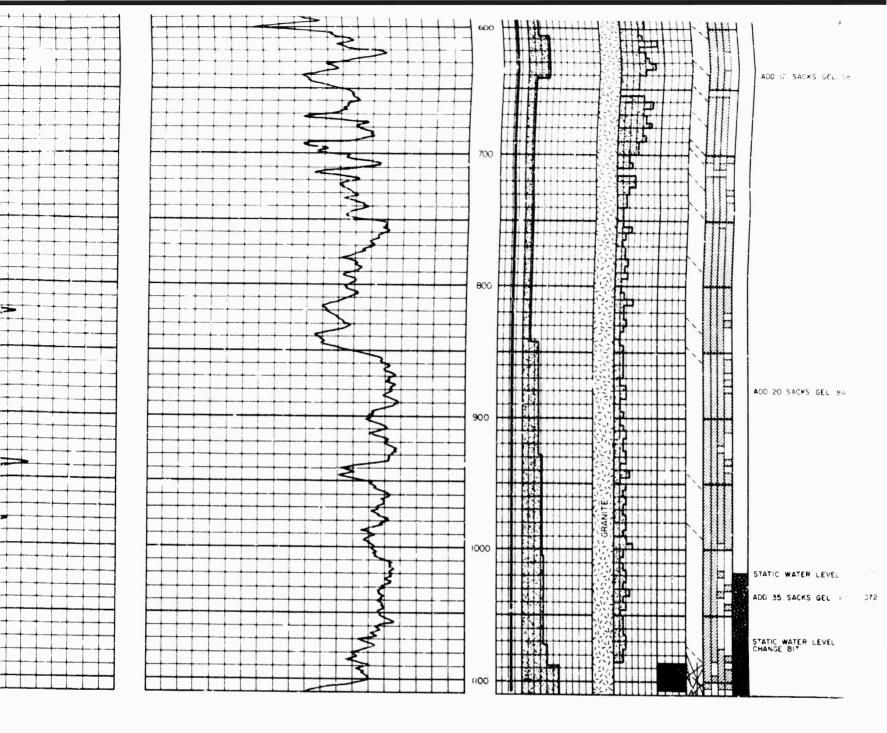
E



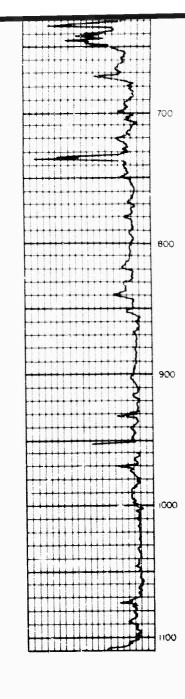
SANT TRINGS RANGE CHURCH TUNTY, NEVADA

GEOPHYSICAL LOGS Schlumberge Well Surveying Corp.
GEOLOGIC LOG L Agenbroad
DRAWN BY D Poul









NEVADA BUREAU OF MINES

MACKAY SCHOOL OF MINES

UNIVERSITY OF NEVADA

PROJECT SHOAL

GEOPHYSICAL LOGS AND GEOLOGIC LOG PM HOLE NO. 3

SAND SPRINGS RANGE CHURCHILL COUNTY, NEVADA

GEOPHYSICAL LOGS Schlumberger Well Surveying Corp
GEOLOGIC LOG L Agenbroad
DRAWN 8Y D Paul

